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OAK RIDGE NATIONAL LABORATORY

UNION CARBIDE

Blast Tests of Expedient Shelters in the Misers Bluff Event

FINAL REPORT • JANUARY 1980

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Expedient shelters were blast-tested by a conventional explosion equivalent to a 0.2 KT nuclear explosion. The estimated survivabilities in a large nuclear explosion are: (1) improved Small-Pole Shelter, 345 kPa (50 psi); (2) triangular entryway and blastdoor made of poles, 173 kPa (25 psi); (3) Chinese A-Frame Pole Shelter, 48 kPa (7 psi); and (4) lightly shored Pole-Covered Trench Shelters, 103 kpa (15 psi).

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(DETACHABLE SUMMARY)

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ENERGY DIVISION
Solar and Special Studies Section

FINAL REPORT - JANUARY 1980

BLAST TESTS OF EXPEDIENT SHELTERS IN THE MISERS BLUFF EVENT[*]

by

Cresson H. Kearny, Conrad V. Chester and Edwin N. York[†]

for

Federal Emergency Management Agency
Washington, D.C.   20472

Interagency Agreement DOE 40-679-78 and DCPA01-78-C-0171

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This report has been reviewed in the Federal
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Date Published: April 1980

[*]This report also is the Defense Nuclear Agency (DNA) Project Officer's
Report (POR) No. 7019 for Oak Ridge National Laboratory to fulfill DNA's
requirement that all participating organizations issue a Project Officer's
Report.

[†]Boeing Aerospace Corporation.

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DETACHABLE SUMMARY

In test explosions conducted by the Defense Nuclear Agency (DNA) in
1973 and 1976, Oak Ridge National Laboratory (ORNL) civil defense research-
ers had blast-tested a variety of expedient shelters and several items of
expedient life-support equipment. Similar blast testing was continued in
Event II-I of DNA's MISERS BLUFF Series. In this test, five types of
expedient shelters (that had been prefabricated by ORNL and installed by
Boeing Aerospace Company) were subjected to air-blast effects equivalent
to those produced by the surface-bursting of a 0.2-kiloton nuclear
weapon. This MISERS BLUFF explosion was detonated in an Arizona desert
on June 28, 1978.

The design and construction of the shelters listed below are described
and illustrated, as is their condition after the explosion. Although it
is difficult to extrapolate from the blast damage to buried structures
caused by a 0.2-kiloton explosion up to the damage that would result from
a megaton-range explosion, the following conclusions appear realistic:

1. A Small-Pole Shelter should afford dependable protection at the
    45-kPa (50-psi) overpressure range from a large nuclear surface
    burst if it has:

    (a) a layer of readily crushable material about 15 cm (6 in.)
         thick,

    (b) 1.5 m (5 ft) of earth cover,

    (c) a floor of poles, and

    (d) the other improvements incorporated in the model undamaged
         (except for its blast door) in the MISERS BLUFF Event at
         621 kPa (90 psi). [The expedient blast door that was
         undamaged at 366 kPa (53 psi) in DNA's 571.5-metric ton
         (630-ton) DICE THROW explosion should be used.]

2. The improved design of triangular entryway and blast door of
    hewn poles, tested at 304 kPa (44 psi), should provide depend-
    able protection from large nuclear weapons at the 173-kPa (25-
    psi) overpressure range. This ORNL-designed entryway was an
    addition to the room of the Chinese A-Frame Pole Shelter.

3. The room of the Chinese A-Frame Pole Shelter, because of the probable squeezing in and/or collapse of the unshored earth walls of the lower parts of its main room, is unsafe for blast protection at overpressures produced by large nuclear explosions above about 48 kPa (7 psi).

4. Lightly shored Pole-Covered Trench Shelters of the stronger designs tested in the MISERS BLUFF Event can provide reliable blast protection up to 104 kPa (15 psi), provided they are equipped with expedient blast doors of types proven strong enough in prior blast tests.

5. Neither of the very lightly constructed A-frame shelters made of 3/4-in. plywood (19-mm) and 2 x 4 in. boards (actually 41 x 92 mm) is strong enough for use even as fallout shelters if covered with 0.9 m (3 ft) or more of earth.

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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iii

CONTENTS

LIST OF FIGURES

Page

ACKNOWLEDGMENTS

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ABSTRACT

In test explosions conducted by the Defense Nuclear
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types of expedient shelters (that had been prefabricated by
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The design and construction of the shelters listed
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late from the blast damage to buried structures caused by a
0.2-kiloton explosion up to the damage that would result
from a megaton-range explosion, the following conclusions
appear realistic:

1. A Small-Pole Shelter should afford dependable protec-
    tion at the 345-kPa (50-psi) overpressure range from a
    large nuclear surface burst if it has:

    (a) a layer of readily crushable material about 15 cm
         (6 in.) thick,

    (b) 1.5 m (5 ft) of earth cover,

    (c) a floor of poles, and

    (d) the other improvements incorporated in the model
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         MISERS BLUFF Event at 621 kPa (90 psi). [The
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1. BACKGROUND AND SCOPE

1.1 Expedient Shelters

Oak Ridge National Laboratory (ORNL) blast-tested a variety of expedient shelters* in two of Defense Nuclear Agency's prior major events, MIXED COMPANY and DICE THROW.[1,2] These tests and the blast tests of other organizations proved not only that excellent fallout protection but also surprisingly good blast protection can be provided by expedient shelters made of fresh-cut poles, boards, doors, and/or other widely available materials--provided these yielding structures are covered with an adequate depth of earth[†] to attain effective earth arching.

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*An "expedient shelter" is one that can be built in 48 hr or less by following fieldtested instructions and using widely available materials and tools.

†Because many Americans believe the word "soil" means only soft earth in which plants grow, and because ORNL shelter building instructions are written primarly for nontechnical citizens, "earth" is used instead of "soil" in both ORNL instructions and reports.

In 1978, ORNL planned to install and blast test several improved
designs of expedient shelters and a prototype of a prefabricated steel
shelter in the Air Force Weapons Laboratory's Dynamic Air Blast Simulation
(DABS) test. This test was to have produced the impulse and blast-wind
effects of a 125-kiloton surface burst, and would have provided an oppor-
tunity to evaluate shelters under conditions more nearly comparable to
the effects of megaton explosions than those that occurred during prior
blast tests. However, the DABS test was canceled.

The prefabrication was already under way of the ORNL expedient
shelters to be tested. Therefore, in order to obtain some useful infor-
mation from these shelters, an agreement was reached with Boeing Aerospace
Company to install them in ground that had been assigned by Defense
Nuclear Agency to Boeing in MISERS BLUFF, Event II-I. As a result of
this agreement, six expedient shelters of five types were subjected to
blast effects at the predicted 690-kPa (100-psi), 345-kPa (50-psi), anc'
104-kPa (15-psi) overpressure ranges. In addition, prototypes of factory-
made, corrugated-steel, cylindrical shelters produced by the Donn Corpora-
tion of Westlake, Ohic, were tested at 1035 kPa (150 psi), 690 kPa (100
psi), and 345 kPa (50 psi). The tests of these factory-made shelters
have been given in detail in two reports prepared and published by the
Donn Corporation[3,4] and will be included in a DNA report.[5] These reports
also cover Donn Corporation shelters tested in MISERS BLUFF, Event II-II.

1.2 Prefabricated Steel Shelters

The authors' realization of the difficulties that most Americans
would experience if they were to build good expedient _blast_ shelters has
reinforced our belief that the United States at the very least should
develop and blast test a design of blast shelters that (1) could be
factory produced by the millions at a reasonable cost, (2) would be
compact and relatively light for efficient storage and transport, and (3)
could be quickly assembled, installed in a trench, and covered with earth
by unskilled persons. Therefore, when the Donn Corporation expressed
interest in developing such a prefabricated shelter, the authors contribu-
ted technical advice.

The ORNL shelter project paid for only a small fraction of what it cost the Donn Corporation to develop and blast test prototypes of its prefabricated steel shelters.

2. PRINCIPAL OBJECTIVES

To determine whether new designs of blast shelters actually are improvements, rigorous blast testing is essential. Prior blast tests[1,2] had indicated that several more improvements were needed in the designs of American expedient shelters and of Russian and Chinese expedient shelters previously improved and then blast tested by ORNL.

The principal objectives of ORNL's participation in MISERS BLUFF were:

1. To obtain additional field data on the blast hardness of the two most promising improved designs of expedient shelters (ORNL-improved versions of the Russian Small-Pole Shelter and of the Chinese A-Frame--or "man"--Shelter). This was to be accomplished by subjecting them to approximately twice the air-blast over-pressures [690 kPa (100 psi) and 345 kPa (50 psi) respectively] they had withstood in prior blast tests. These shelters could prove important, especially to essential workers who should remain in high-risk areas during a crisis threatening nuclear attack and to military personnel. The improved blast-protective designs depend primarily on attaining more effective earth arching by first covering them with easily crushable, widely available materials and then covering them with earth. Recent experiments[*] and analytical calculations indicate that earth compaction and earth arching around earth-covered objects are important factors in protecting them against damage from blast effects. For expedient shelters to resist large blast loads, they must be flexible enough to yield until the surrounding earth has compacted enough to permit earth arching to carry the blast loads around the structure. One way of providing adequate flexibility of the structure is to surround it with straw or brush to provide a cushioning, crushable outer layer. A layer of small brush was placed around two of the shelters, and inner-spring mattresses were used to test for efficiency in improving the blast-hardness of buried shelters. Furthermore, to minimize blast-induced stresses and to prevent excessive blast-wind scouring of their earth covers, all shelters were installed in trenches deep enough so that the top of the specified thicknesses of earth covering would be approximately at the original ground level.

2. To evaluate the blast hardness of three improved or new types of expedient shelters designed for ease of construction by untrained

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[*]Especially the blast tests conducted by Boeing (ref. 6) and ORNL (ref. 2) as participants in the 571.5-metric ton (630-ton) ANFO explosion of DNA's DICE THROW series.

citizens. These shelters would require minimum amounts of widely available materials and should be capable of withstanding all blast effects at the 104-kPa (15-psi) overpressure range.

3. To contribute, mainly by providing technical advice and some instrumentation, to the blast testing of the Donn Corporation's prefabricated steel shelters.

The Donn Corporation of Westlake, Ohio designed and built more prototype steel shelters, blast doors, and blast valves than anticipated. This corporation also was able to test its full-scale prototypes not only in MISERS BLUFF Event II-I, but also in the six-shot Event II-II. Since these extensive blast tests are covered in detail in the Donn Corporation's two published reports,[3,4] only brief mention will be made in this report concerning tests of prefabricated steel shelters, other than in Appendix B. The photos in Appendix B indicate the potential capability of the United States to mass-produce blast shelters for tens of millions of unprotected Americans.

3. LIMITATIONS

The Event II-I explosion of the MISERS BLUFF Series was detonated on June 28, 1978, near Lake Havasu City, Arizona (see Figs. 3.1, 3.2, and 3.3). It produced the more important blast effects of only an approximately 0.2-kiloton nuclear explosion. Furthermore, the extremely light, alluvial soil of the test site was so compressible that the short-duration, low-impulse blast pressures produced at the surface were attenuated in depth even more than would have been the case in most soils. Therefore, the results of the MISERS BLUFF blast test require considerable extrapolation to determine the probable effects of long-duration, high-impulse effects from megaton explosions.

ORNL PHOTO 4162-78
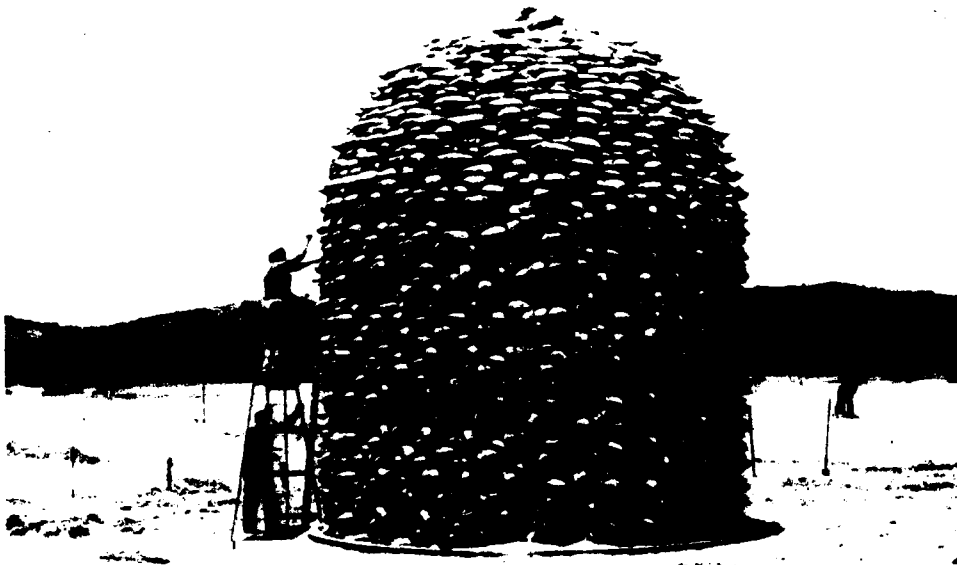
Fig. 3.1. Bags of ammonium nitrate fuel oil explosive (120 tons of ANFO) stacked and ready to be detonated in MISERS BLUFF Event II-I.

ORNL PHOTO 4176-78

Fig. 3.2. Poorly formed mushroom cloud from the explosion.

ORNL PHOTO 4165-78

Fig. 3.3. Crater produced by the explosion.

4. INSTRUMENTATION AND METHODS USED TO OBTAIN TEST DATA

4.1 Blast Overpressures

Inside the shelters, blast overpressures were measured by yielding-foil membrane blast gauges.[7] These passive gauges were developed at ORNL and, as in prior tests, performed well at the low overpressures to be measured inside closed shelters. All the wooden shelters at MISERS BLUFF were tested closed.

Outside the shelters, the peak overpressures were calculated by interpolation from the overpressures measured by the transducers installed by the Waterways Experiment Station, Corps of Engineers, Department of the Army, on a radial line extending outward from ground zero (GZ).

Empty 1-gal metal cans (rectangular, thin-wall cans of the common type) were used as backup pressure gauges. This type of 1-gal can was calibrated for use as a pressure gauge by exposing several of them to free-field overpressures from the MISERS BLUFF test. A set of cans was exposed to overpressures ranging from 10 kPa (1.5 psi) to 104 kPa (15 psi). Deformation of the cans was determined by filling them with water and weighing them before and after the calibration test. The cans were found capable of detecting a minimum overpressure of approximately 28 kPa (4 psi).

None of the cans placed in the ORNL wooden shelters tested in Event II-I of MISERS BLUFF showed any measurable deformation; this indicated that no peak overpressure inside a wooden shelter was as high as 28 kPa (4 psi).

4.2 Transient Motions and Permanent Movements

Transient motions and permanent movements of the roofs, walls, and some other parts of the shelters were measured by the following methods and devices:

1. Wooden scratch gauges made of split dowels, with the ends of the dowels securely attached to a well-set post and a wall, or to opposite walls, or to ceiling and floor. Figure 4.1 shows a scratch gauge of this type designed to be placed in earth and to

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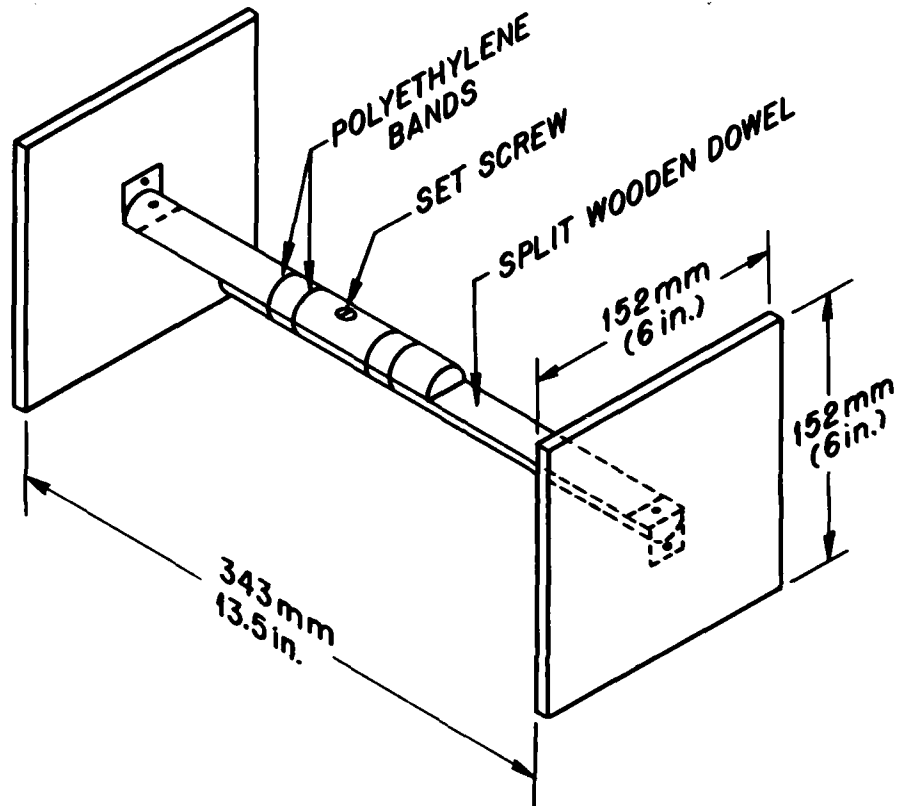
Fig. 4.1. Scratch gauge of type used to measure earth movements.

measure earth movements. After the ends of a scratch gauge are securely attached, the setscrew is tightened until its sharp point slightly penetrates the part of the gauge in which both transient motion and permanent movement will cause the point to leave a scratch mark.

2. Metal scratch gauges made of two tubes sized so that the end of one slips into the other.

3. Measurements of reductions in ceiling heights, taken preblast and postblast, between the top of a stake in an earth floor (or a point on a wooden or steel floor) and the ceiling.

4. Measurements between points on opposite walls.

5. Measurements of permanent horizontal movement of a ceiling relative to the floor of a shelter and of the permanent tilt of walls. These measurements were made by using a plumb bob positioned preblast so as to hang directly over a fixed point on the floor.

4.3 Blast Damage to Structures

Blast damage to all structural parts of shelters, to unshored earth walls, to earth floors, and to water storage containers was determined primarily by still photographs and observations made preblast and postblast.

5. TEST DATA RECOVERED

As a result of the shelters having been placed at locations where only minor structural damage was expected and these expectations having been proved valid, all pressure gauges were recovered and read. Due to malfunctions, only 90% of the scratch gauges in the ORNL shelters recorded all of the information desired.

6. SMALL-POLE SHELTERS AT 621 kPa (90 psi)

6.1 Purpose

In earlier blast tests,[1,2] Small-Pole Shelters had been essentially undamaged by blast effects of up to 366 kPa (53 psi). This type of expedient shelter is considered best for preventing injury to persons in areas subjected to severe blast. Therefore, to evaluate the practicality of improved versions of the Small-Pole Shelter, two prototypes were tested at the predicted distance [77.1 m (253 ft) from ground zero] for 690-kPa (100-psi) blast effects. The measured overpressure was 621 kPa (90 psi).

The two full-scale prototypes tested were made of lodgepole pine poles, freshcut in Colorado, and cut to the specified lengths before being trucked to Arizona. This was done to simplify and expedite installation under the extremely hot and dusty conditions at the desert test site. These two prototypes are described in Secs. 6.2.1 and 6.2.2.

6.2 Construction of the Two Shelters

6.2.1 A complete room, including an entryway and blast door

A complete room, including entryway and blast door, of an improved version of the Small-Pole Shelter was installed. This version is illustrated in Figs. 6.1 and 6.2. The following modifications were incorporated.

● To save money in this test, only the entryway shown on the left in Figs. 6.1 and 6.2 was built. [Two entryways and a Kearny Air Pump (KAP) are essential in warm or hot weather if a factory-made, big-volume ventilating pump is not available and a second ventilation opening is not provided. This ventilating is necessary to prevent the body heat and water vapor from the occupants of the fully occupied shelter from causing dangerous, possibly lethal, heat-humidity conditions.]

● To prevent most shelter occupants from receiving doses of initial nuclear radiation that would be even temporarily incapacitating, the depth of earth cover was increased from 0.9 m (3 ft) to 1.5 m (5 ft), and the

Fig. 6.1. Plan and elevation of a Small-Pole Shelter designed for excellent protection against fallout radiation.
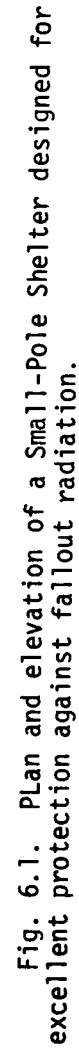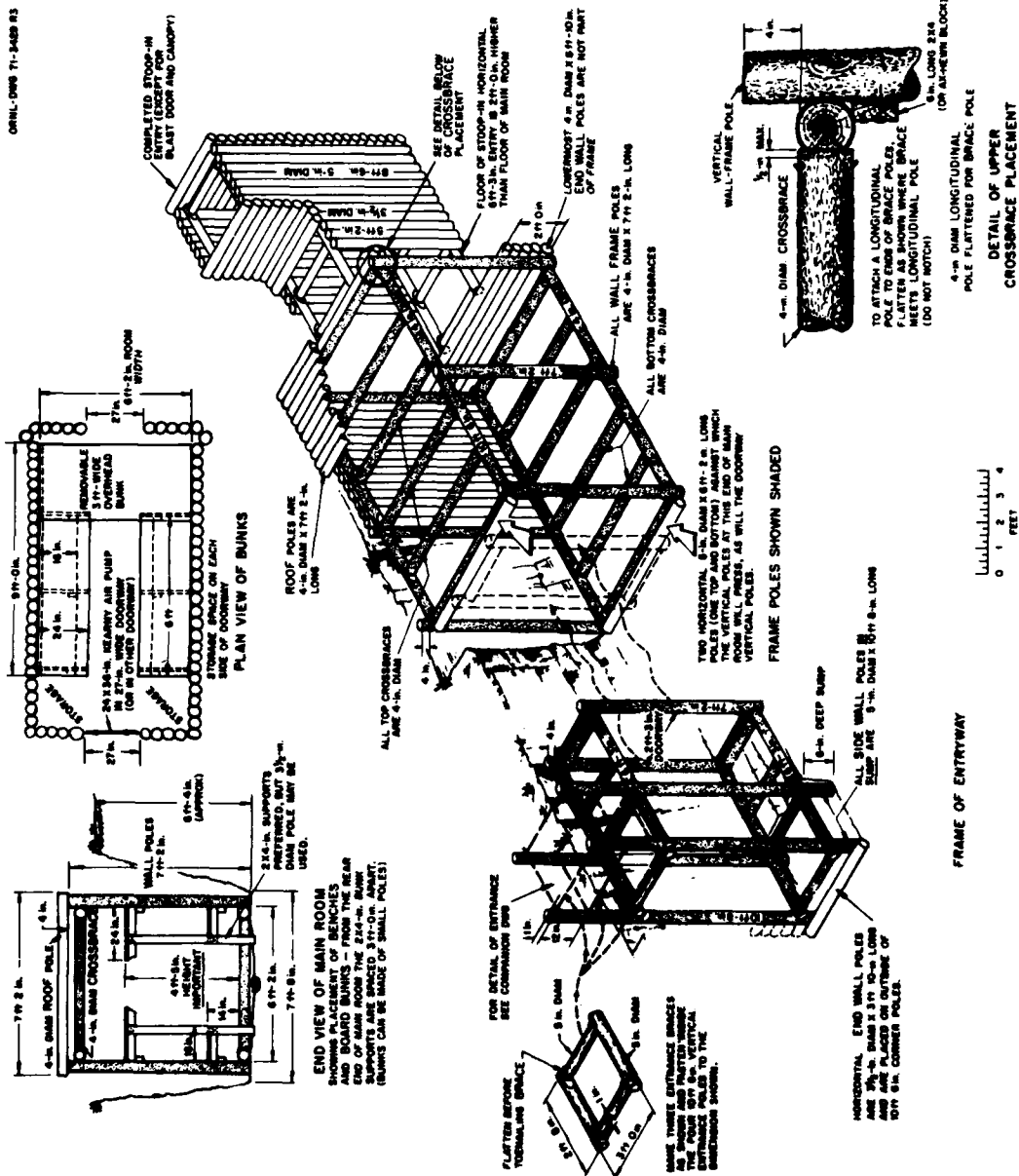
Fig. 6.2. Pictorial view of Small-Pole Shelter designed for excellent protection against fallout radiation.

horizontal part of the entryway was increased from 1.9 m (6 ft 3 in.) to
3 m (10 ft), as illustrated by Figs. 6.3 and 6.4. Figure 6.4 also shows
additional shielding placed in the entry. The increased shielding is
needed to prevent occupants of the shelter from receiving initial radia-
tion doses greater than 100 rems at the 345-kPa (50-psi) overpressure
range from a 1-megaton (1-MT) or larger surface burst.[*] Damp earth could
be substituted for the water containers shown in Fig. 6.4; the water in
damp earth would supply the hydrogen atoms needed for efficient attenua-
tion of initial neutron radiation.

● To prevent earth under the shelter from being squeezed up into the
shelter by the blast-induced pressure in the earth, the shelter and its
entry had a solid floor of poles (see Fig. 6.3). In a previous blast
test[2] at 366 kPa (53 psi) the underlying earth was destabilized, and part
of a bare earth floor was squeezed quickly upward by blast effects of the
explosion, that produced airblast effects of a 1-kiloton (1-KT) nuclear
surface burst.

● To provide an adequately strong yet not too heavy expedient blast
door capable of withstanding 690 kPa (100 psi), one was designed, built,
and installed (see Fig. 6.5). This door was 107 cm (42 in.) wide and 122
cm (58 in.) long. It was made with seven beams each 114 cm (44-3/4 in.)
long; the beams were 2 x 6 in. (41 x 143 mm) boards.[†] Spacer boards [2 x
6 in. (41 x 143 mm)] separated the seven beams, so as to result in a
coarse honeycomb structure, with two thicknesses of 3/4-in. (19-mm)
exterior plywood epoxied and nailed on top and bottom. Since this door
was very badly damaged at 621 kPa (90 psi) and is much more difficult to
make than the 11.4-cm-thick (4-1/2-in.) plywood door that was undamaged at
366 kPa (53 psi) in a higher-impulse blast test,[2] the all-plywood door is
recommended.

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[*]The shielding calculations were made by Lewis V. Spencer, a physicist
with the Radiation Physics Division, Center for Radiation Research, Nation-
al Bureau of Standards, Washington, D.C.

[†]A "2 by 6" measures 1-5/8 by 5-1/2 in.
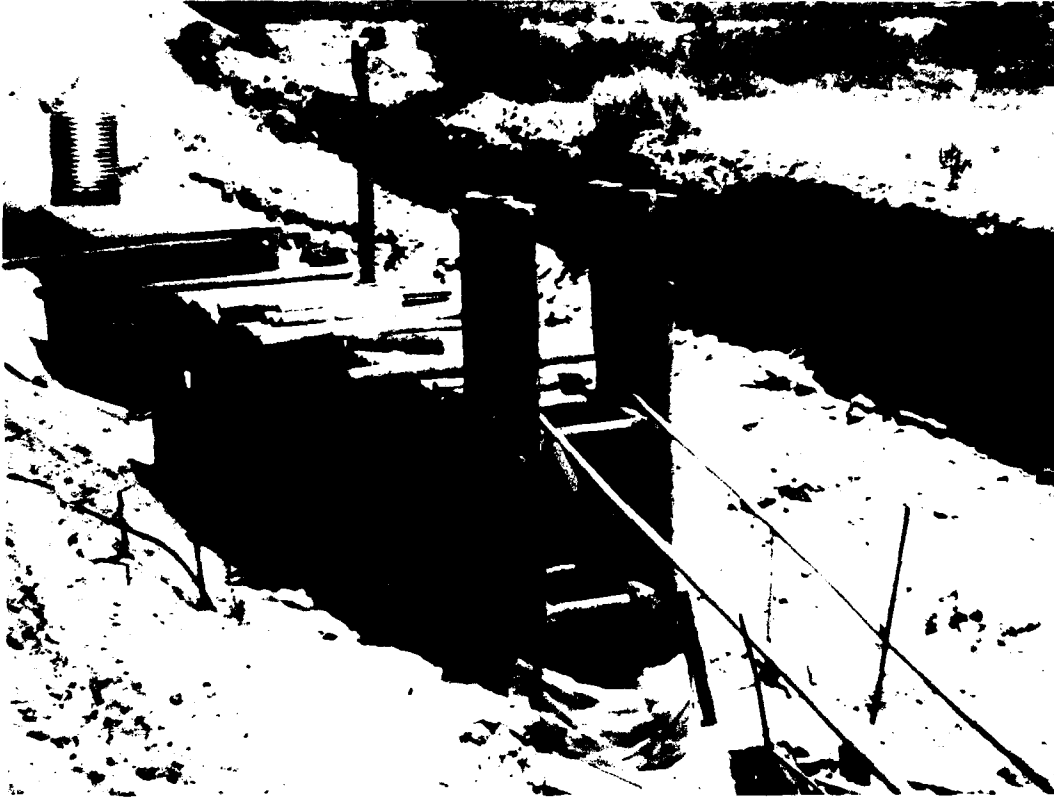
Fig. 6.3. Improved Small-Pole Shelter being built in a 4-m-deep
(13-ft-deep) trench--deep enough to permit covering its roof with 1.5 m
(5 ft) of earth, with the final surface at the preconstruction ground
level. Back of the shelter with the half-finished entry is a detached
room of a Small-Pole Shelter. In the rear is the corrugated-metal,
cylindrical entry of a factory-built shelter of the Donn Corporation.

ORNL-DWG 78-18835

BLAST DOOR
4 3/4 in. THICK
PLYWOOD

BLAST PROTECTOR
LOG

9 in.

WATERPROOF "BURIED ROOF"

GROUND LEVEL

EARTH COVER 5 ft

CLOTH OR PLASTIC COVER

CRUSHABLE MATERIAL 6 in. THICK ON ROOF

14 ft - 0 in. POLES (NOT SHOWN)

WATER

WATER

KAP (24 in. x 36 in.) IN ENTRY WAY DOORWAY

EARTH BAGS

7 ft - 2 in. CEILING OF 3-ft-WIDE ENTRY

3 ft

3 ft - 6 in.

BAGS OF EARTH
2 ft
IN DOOR WAY

SUMP

DRAINAGE DITCH

ENTRY 11 ft

SHELTER ROOM

Fig. 6.4. Small-Pole Shelter adequately shielded against initial nuclear radiation. This sketch is a simplified vertical section through the centerline of one end of the shelter.

ORNL PHOTO 4164-78

Fig. 6.5. Expedient blast door made of lumber and plywood and designed to withstand 690-kPa (100-psi) blast effects. Note the four blast-protector logs around the door.

● To promote more effective earth arching over and around the shelter, it was covered with easily crushable, widely available materials: brush covered with cloth or polyethylene, or innerspring mattresses (see Fig. 6.6). (To keep the flourlike powdery earth from running through cracks between poles, the poles were covered with polyethylene before being covered with the crushable materials.)

● To measure the transient and permanent movements of all important parts of the shelter, numerous scratch gauges were installed, as illustrated in Fig. 6.7. The ventilation pipe in the foreground could be raised with a jack after the blast. The sloping wires pictured in Fig. 6.7 were used to stabilize the shelter during construction; they were cut before the explosion.

6.2.2 A detached room

A detached room, with horizontal poles completely closing its two ends, was built with the same features as those described in Sec. 6.2.1, except that it had an earth floor. The purpose of this earth-floored room tested at a predicted 690 kPa (100 psi) was to see whether there is need for a solid, substantial shelter floor at high overpressures.

6.3 Test Results

6.3.1 The complete room and entry after the blast

● The blast door was almost broken in two (see Figs. 6.8 and 6.9), but it had prevented the shock wave or consequential overpressure from entering the shelter. All of its 2 x 6 in. (41 x 143 mm) beams were broken, as was the plywood on its lower side. However, since the door had been secured with only two 60-penny (15-cm, or 6-in.) nails at the lower ends of its hold-down wires, the negative overpressure tore the door open. (In a previous blast test, fourteen 60-penny nails were used to nail a flattened, horizontal pole to the vertical poles on one side of the entry, and the hold-down wires were connected to this strongly nailed horizontal pole. This attachment system proved to be dependable, as described and pictured in Fig. 6.10 and an earlier blast-test report.[2])

ORNL PHOTO 3275-79

Fig. 6.6. Small-Pole Shelter being covered with mattresses and other readily compressible materials, to promote protective earth arching. The steel pipe is the below-ground housing of a raisable ventilation pipe that after the blast was raised so that its upper end was well above ground level. In the background are two cylindrical, corrugated steel entrys of a factory-made shelter of the Donn Corporation.

ORNL PHOTO 4175-78
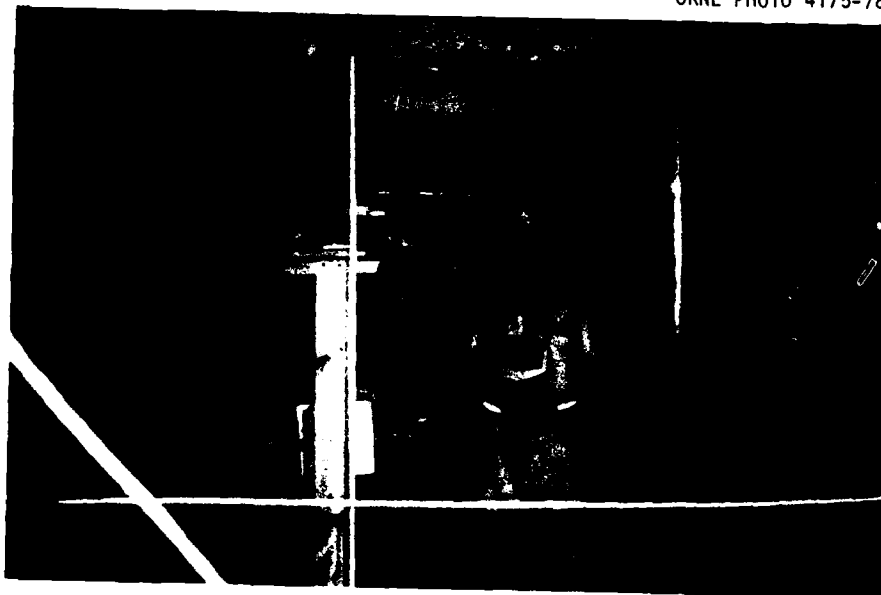
Fig. 6.7. Preblast interior of the Small-Pole Shelter's room, showing scratch guages, post in center of room to which some scratch gauges were attached, and the raisable ventilation pipe.

Fig. 6.8. Postblast view of the poorly secured blast door that excluded shock waves and positive overpressure but was torn open by the negative overpressure of approximately 35 kPa (5 psi). Several pounds of dry earth were blown into the shelter.

ORNL PHOTO 3992-78

Fig. 6.9. Expedient blast door that excluded 621 kPa (90 psi) overpressure, although almost broken in two. It first had been violently opened by the negative overpressure and then partially shut by the afterwinds. Note the hinges (made of strips cut from automobile tire treads) that had been torn loose from the vertical part of the door's hinged end.

ORNL-DWG 73-1063R

WIRE SAFETY LOOP

ALL NAILS BENT OVER AND CLINCHED

SHORT SECURITY-CORD TIED TO PROP-STICK.

TWO STRANDS NO 9 WIRE.

FOUR STRANDS NO 9 WIRE.

WIRE BINDING AT 'V' OF BRIDLE. 4 IN BELOW CONNECTIONS TO DOOR.

BLAST-PROTECTION FRAME (NOTCHED LOGS — LIKE LOG CABIN).

SIMPLER FRAME CORNER, REQUIRING THREE 60-PENNY NAILS

8 STRANDS NO 9 WIRE

BLAST DOOR
SHOWING WIRE HOLD-DOWN BRIDLE AND PROP-STICK.

PUSH BOTTOM OF OPEN DOOR AWAY FROM ENTRYWAY SO IT RESTS ON HINGES, TO MAKE RAPID CLOSING POSSIBLE.

WIRE SAFETY LOOP HOOKED OVER 3 TO 4-in DIAM SAFETY POST

FIRST EACH CAR-TIRE HINGE IS NAILED TO DOOR WITH SIX 16-PENNY NAILS (CLINCHED). THEN A 2X6-in BOARD IS NAILED OVER HINGES WITH 40-PENNY NAILS (CLINCHED)

CAR-TIRE HINGE 4 in X 18-in LONG

OUTSIDE 12 in OF EACH VERTICAL POLE IS FLATTENED FOR HINGE ATTACHMENT WITH NINE 20-PENNY NAILS PER POLE

TOP OF PROTECTOR-LOGS 2-in. ABOVE TOP OF CLOSED DOOR.

STICK DRAIN UNDER PROTECTOR LOGS — BUNDLE OF CLEAN STICKS WITH PLASTIC WRAPPED AROUND OUTSIDE

CROSS SECTION
SHOWING HINGE OFF-SET AND DRAINAGE — DOOR SHOWN IN SAFETY POSITION

BRIDLE SPACE

PROP-STICK

8-in DIAM LOOP OF BLAST-PROTECTION FRAME ARE PLACED 5 TO 6 in. OUTSIDE ENTRYWAY.

PULL-CORD TIED TO PROP-STICK

4 ft 0 in.

24 in.

8 - 2X6-in X 4 ft 0-in-LONG BOARDS FOR 10 psi OVERPRESSURE (ROUGH LUMBER PREFERRED).

THREE - 2X6-in BOARDS FOR 10 psi.

TWO 40-PENNY NAILS PER 4-in BOARDS.

ONE 18-in-LONG CAR-TIRE HINGE PER VERTICAL POLE.

BLAST DOOR
SHOWN IN READY POSITION

LOOP OF EASILY BROKEN STRING TO HOLD HANDLE UP IN MAXIMUM TIGHTENING POSITION.

CORD TIED TO LINK AND SUPPORTING LOAD-BINDER IN READY POSITION (CHEST HEIGHT).

LINKAGE BETWEEN UPPER HOOK AND SWIVEL TAPED OR BOARD TO STIFFEN AND HOLD HOOK AND HOLD HOOK FACING WIRE LOOP

LOWER HOOK TAPED OR BOARD TO LOWER WIRE LOOP

8 STRANDS OF NO 9 WIRE FOR ANY BLAST OVER-PRESSURE).

WIRE LOOP AT END OF 8 STRANDS OF NO 9 WIRE CONTAINING INTO WIRE Y-BRIDLE

LOAD-BINDER INSTALLED FOR 4-sec HOLD-DOWN OF BLAST DOOR.

8 STRANDS OF NO 9 SOFT STEEL WIRE.

5-in DIAM POLE-CUT-TEN ONE SIDE BY REMOVING 1½-in. AND NAIL WITH TWO 60-PENNY NAILS TO EACH VERTICAL POLE

BOTTOM OF ENTRYWAY

Fig. 6.10. Expedient blast door that can be closed and secured in 4 sec. A much stronger door than this, but with the same holddown system, was undamaged and was not opened or loosened by the blast effects at 366 kPa (53 psi) from an explosion five times as powerful as the MISERS BLUFF shot.

● The movements between the undamaged room ceiling and the undamaged room walls relative to the fixed scratch gauge post (see Fig. 6.7) are listed below.

Location	Transient motion compression	Permanent movement compression
1. Top of post to ceiling	87.3 mm (3-7/16 in.)	33.3 mm (1-5/16 in.)
2. Top of post to rear wall	15.9 mm (5/8 in.)	13.5 mm (17/32 in.)
3. Top of post to side wall away from GZ	3.2 mm (1/8 in.)	Zero - no motion

● A horizontal scratch gauge at the midpoint of the horizontal walk-in entry showed transient motions of 23.8 mm (15/16 in.) compression, 3.2 mm (1/8 in.) elongation, and a permanent movement of 8.7 mm (11/32 in.) compression. At the center of the main room the vertical scratch gauge showed 34.9 mm (1-3/8 in.) transient compression, 3.2 mm (1/8 in.) transient elongation, and 15.9 mm (5/8 in.) permanent compression. The horizontal scratch gauge showed 25.4 mm (1 in.) transient compression with 7.9 mm (5/16 in.) permanent compression.

● It appears that an air gust entered the shelter. An empty 1-gal can sitting upright at the horizontal entry had tumbled about 1 m (3 ft) down the entryway. Another can at the middle of the horizontal entry was tipped over but not moved sideways. A can in the middle of the main room was not moved. The gust was not associated with a shock wave, since the entryway and main room overpressures (measured by membrane blast gauges) were essentially the same. As previously mentioned, the blast door hold-down was inadequate to resist the negative pressure pulse, as proved by the blast door being found partly open immediately after the detonation. It is probable that the shelter air flowed out during the negative pressure phase, and inward-blowing outdoor air, which rushed into the shelter after the negative phase was over, created enough drag to move the cans inward from the entrance.

● Overpressures measured inside the shelter proved that the blast door survived the positive pressure phase, since the measured overpressures inside the complete shelter were only slightly greater than those inside

the detached shelter room, which had no entrances [about 28 kPa (4.0 psi) compared with 26 kPa (3.75 psi)]. The overpressure in the horizontal entryway near the vertical entry was 27 kPa (3.9 psi). All overpressures measured inside the ORNL expedient shelters and the Donn Corporation's steel shelters tested in Event II-I of MISERS BLUFF are listed in Appendix A.

● Dust in quantities that could have proved injurious to shelter occupants (without masks or cloths to protect their noses and mouths) entered through the "sucked-open" door. The only visible damage to the main room was a small amount of fine silt that flowed in at the rear corners of the main room. Inspection showed that the top rear wall log moved relative to the end ceiling log with enough displacement to tear the plastic cover sheet. About 1 gal of silt entered at one corner and about 2 gal at the other corner.

● All shelter walls extending perpendicularly to a radius from GZ had their tops permanently tilted away from GZ. This permanent tilt [a normal result of the permanent component of earth movements at the 621-kPa (90-psi) overpressure range] amounted to about 15 cm (6 in.) for the tops of the 4-m (13-ft) vertical poles of the entry. No damage resulted from this permanent tilting (see Fig. 6.11).

● The gap between the upper ladder brace and the ceiling poles of the shelter room, which was initially 89 mm (3-1/2 in.), was reduced to 64 to 76 mm (2-1/2 to 3 in.). Placing the vertical sidewall poles on the ends of the floor poles thus considerably reduced the tendency of the blast forces on the roof poles to "punch down" the sidewall poles. Actually, such "punching down" of the sidewall poles may be beneficial if it does not result in too great a movement, because such "punching down" permits more soil compaction around the shelter and less direct load on the roof.

● The uppermost rectangular brace of the vertical entry had one of its 13-cm-diam (5-in.-diam) beam poles (that pressed against all of the vertical poles on one side of the entry) rotated enough to partly pull out the nails that connected one end of one of its smaller-diameter compression poles to this beam pole (see Fig. 6.12). [To prevent this risk of failure

ORNL PHOTO 4820-78

Fig. 6.11. Postblast interior view from the shelter room, looking out the horizontal entryway. Note the permanent tilt of the walls to the right (away from GZ), the thick dust, and the overturned empty 1-gal can on the entryway floor.

ORNL PHOTO 3997-78

Fig. 6.12. Postblast photo showing one corner of the uppermost
rectangular brace of the vertical entry, illustrating how one of its 15-
cm-diam (5-in.-diam) beam poles had been rotated and had started to pull
loose from its smaller-diameter compression pole, shown on the lower
left.

in the future, the drawings (Figs. 6.1 and 6.2) have been changed to
specify that all four poles must be 13 cm (5 in.) in diameter.]

6.3.2 Detached room of a Small-Pole Shelter with an earth floor

For comparison with the Small-Pole Shelter with a solid floor of
poles, a detached room was tested at the same range and measured over-
pressure, about 621 kPa (90 psi). This room was practically identical to
the solid-floored room, except that its floor was bare earth. Obser-
vations on the postblast condition of this room follow.

● The earth was destabilized and pressurized at the 621-kPa (90-psi)
overpressure range by even this small-impulse explosion.[*] As a result,
the earth floor erupted (quickly flowed upward) in two places. The
larger area [46 x 91 cm (18 x 36 in.)] had a maximum mound height of 15 cm
(6 in.). The smaller area [30 x 61 cm (12 x 24 in.)] heaved up about 2.5
cm (1 in.). No discernable eruptions were found on the remainder of the
floor. These amounts of earth flow would not have caused any hazard to
occupants of the shelter, but they are indicative that 690 kPa (100 psi)
is nearing the upper limit for bare dirt floors, even for small explosions.
Higher overpressures would very likely result in much greater earth flow,
with potential hazard to shelter occupants. [In the DICE THROW test
explosion (5 times as large as MISERS BLUFF) at 366 kPa (53 psi), the
upward flow of the more stable earth floor of a Small-Pole Shelter was
slightly more extensive.[2]]

● Ground motions within the shelter were not severe; an empty 1-gal
can, sitting upright on the floor, remained upright. There was no physi-
cal damage detected anywhere in the shelter.

● To measure the movements of the walls and ceiling relative to a
"fixed" object, a vertical pole about 15 cm (6 in.) in diameter had been
set about 1 m (3 ft) into the earth floor. Scratch gauges had been

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[*] No measurements of impulse were made in connection with MISERS BLUFF
at ranges and depths comparable to those of interest to the ORNL shelters.

attached to this post to measure the movements of the walls and ceiling relative to the post. These movements are tabulated below:

Location	Transient motion compression	Permanent movement compression
1. Top of post to ceiling	76.2 mm (3 in.)	38.1 mm (1-1/2 in.)
2. Top of post to rear wall	36.5 mm (1-7/16 in.)	31.8 mm (1-1/4 in.)
3. Top of post to wall toward GZ	27.6 mm (1-1/16 in.)	20.6 mm (13/16 in.)
4. Top of post to wall away from GZ	9.5 mm (3/8 in.)	0.8 mm (1/32 in.)

● Longer scratch gauges had been placed between the side walls, and others had been installed to extend from the ladder-like brace on the floor to the roof poles. [The ladder-like braces had been placed horizontally and served to maintain the specified 188 cm (6 ft 2 in.) separation between the walls.] The vertical midpoint of the side walls had a permanent motion of 23.8 mm (15/16 in.) compression and a transient motion (determined by scratches on two sides of the gauge) of 38.1 and 48.3 mm (1-1/2 and 1-5/8 in.). The floor-to-ceiling scratch gauge showed a permanent movement of 57.2 mm (2-1/5 in.). The transient motion on this gauge failed to register.

The shelter roof poles had been placed on the tops of the sidewall poles. There was a pretest vertical gap of 88.9 mm (3-1/2 in.) between the roof poles and the ladder-like brace below the roof poles. After the blast, this gap was found to have been reduced to 25.4 mm (1 in.) in one corner of the room. The posttest measurements of this gap between the ladder-like brace near the roof and the roof poles are given in Fig. 6.13.

The movements indicate that the vertical sidewall poles, which support the roof poles, were pushed downward into the dirt from 12.7 mm (1/2 in.) to 63.5 mm (2-1/2 in.). This is consistent with the measurement of 57.2 mm (2-1/4 in.) permanent lowering of the middle of the ceiling, some of which may have resulted from permanent bending of the ceiling poles. Such downward movements of a shelter result in more effective earth arching over the shelter and reduce the blast stresses on the shelter itself.

ORNL-DWG 79-14930

51 mm (2 in.)	76 mm (3 in.)
38 mm (1½ in.)	76 mm (3 in.)
25 mm (1 in.)	64 mm (2½ in.) → GZ
25 mm (1 in.)	51 mm (2 in.)
25 mm (1 in.)	51 mm (2 in.)
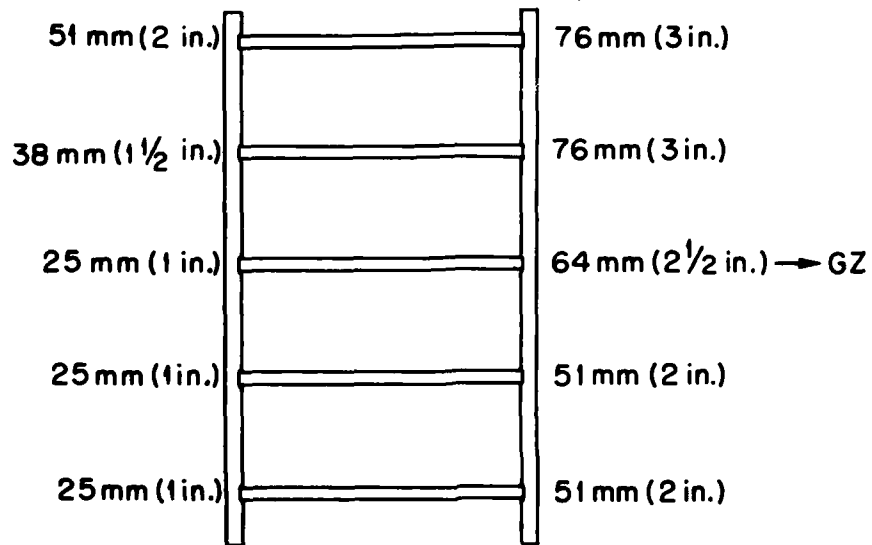
Fig. 6.13. Diagrammatic sketch giving the post blast vertical distances between points on the upper ladder-like brace and roof poles of the detached Small-Pole Shelter room.

● The overpressure measured within this detached, completely buried shelter room was 26 kPa (3.74 psi), which is not high enough to rupture eardrums. However, it is practically as high as the 28 kPa (4.0 psi) overpressure measured inside the room of the complete Small-Pole Shelter with an entry and blast door, and is significantly higher than the 15.9 kPa (2.3 psi) overpressure measured inside the room of the Donn Corporation's steel shelter tested at this same overpressure, 621 kPa (90 psi), measured outdoors (see Appendix A). One explanation for this difference appears to be that the ORNL expedient shelters were covered by quite easily crushable materials ("backpacked"), and that the blast pressure rapidly squeezed air out of this crushable material and into the expedient shelters through the numerous cracks in their roof and wall poles. Or perhaps the greater movements of the poles of the expedient shelters, as compared with the movements of the steel ceilings and walls, resulted in increased overpressures inside the expedient shelters.

6.4 Conclusions and Recommendations

A Small-Pole Shelter built like the above-described version with a floor of solid poles, installed in a trench 4 m (13 ft) deep, and shielded as illustrated should afford good protection up to the 345-kPa (50-psi) overpressure range against all effects of a 1-megaton or larger surface burst.

Step-by-step, well-illustrated instructions for building and living in this shelter should be written and thoroughly field-tested by groups such as firemen and police, many of whom would remain in high-risk blast areas during a nuclear confrontation.

7. CHINESE A-FRAME POLE SHELTER
AT 304 kPa (44 psi)

7.1 Purpose

In an earlier blast test with 5 times as large an explosion as was detonated in Event II-I of MISERS BLUFF, neither the room of a Chinese A-Frame Pole Shelter nor its ORNL-designed triangular, vertical entryway and triangular blast door were damaged at 138 kPa (20 psi).[2] Since this blast shelter requires fewer and smaller poles than does any other expedient blast shelter made of poles of comparable strength and tested in the United States, a further-improved design was tested at the range predicted for 345 kPa (50 psi). This placement resulted in a measured overpressure of about 304 kPa (44 psi).

7.2 Construction

Figure 7.1 shows the start of the building of the main room, with only the lower of its two small-diameter ridgepoles in position. As pictured in Fig. 7.2, the two ridgepoles were wired tightly together, thus securing the sloping wall poles.

The wall poles were each 2.0 m (6 ft 6 in.) long, averaged 7.6 cm (3 in.) in diameter, and were installed with their bottom ends 1.7 m (5 ft 6 in.) apart.

To increase protective earth arching over the shelter, bed sheets were first laid over the wall poles, then a layer of salt cedar brush was placed horizontally over these bed sheets, then a second layer of brush was placed vertically, and finally all this crushable "backpacking" was covered with other dust-tight materials. Figure 7.2 shows cardboard laid over the brush, before being covered with earth.

The shelter room's unshored earth seat and unshored foot trench are pictured in Figs. 7.1 and 7.3. Figure 7.3 gives the preblast dimensions of these lower, unshored parts of the 3-m-long (10-ft-long) shelter room.

The entryway consisted of:

1.   a horizontal, triangular section 1.5 m (5 ft) long, no part of which was an unshored trench (see Figs. 7.4 and 7.5);

ORNL PHOTO 4252-78

Fig. 7.1. Beginning to build the room of the Chinese A-Frame Pole Shelter tested at 304 kPa (44 psi).

ORNL PHOTO 4246-78
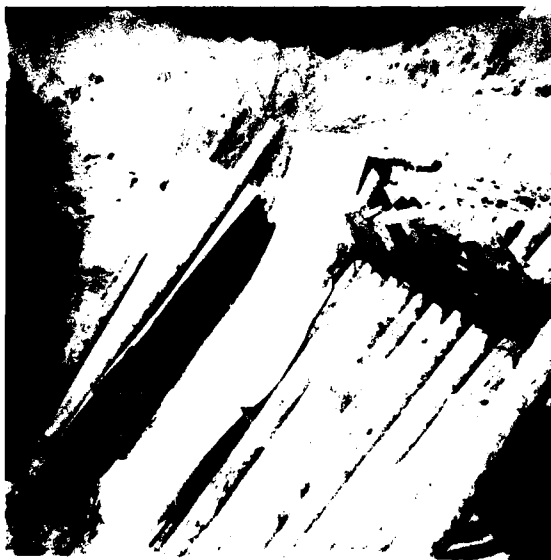
Fig. 7.2. The completed A-frame made of 7.6-cm-diam (3-in.-diam) lodgepole pine poles being covered with two layers of brush for "backpacking." Crushable materials placed over and around a shelter help attain protective earth arching when the earth is subjected to blast pressure.

ORNL-DWG 79-18257
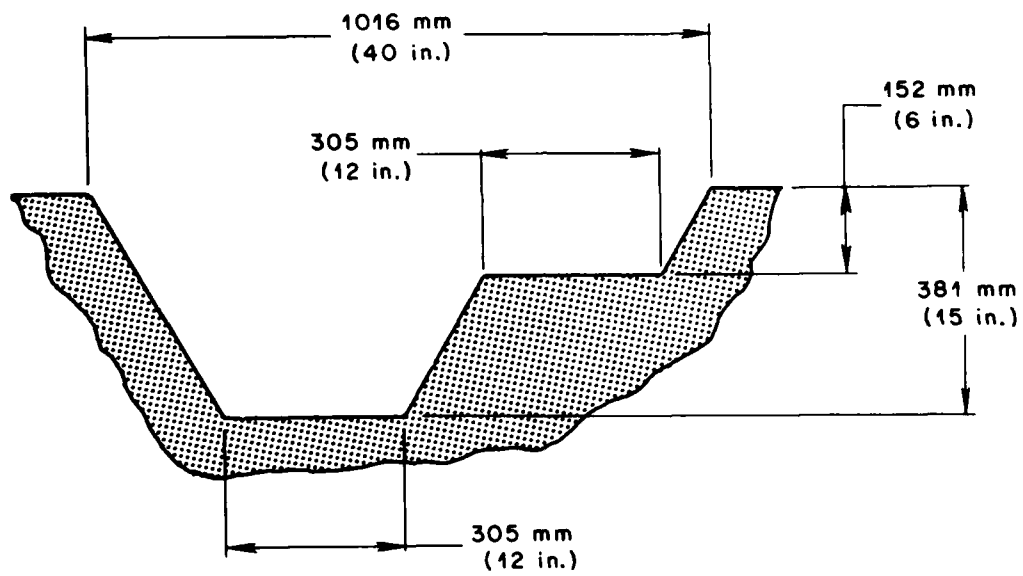
Fig. 7.3. Preblast dimensions of the unshored earth seat and foot trench of the Chinese A-Frame Pole Shelter.

ORNL—DWG 78-14675

TOP VIEW

VIEW LOOKING INTO SHELTER FROM A–A
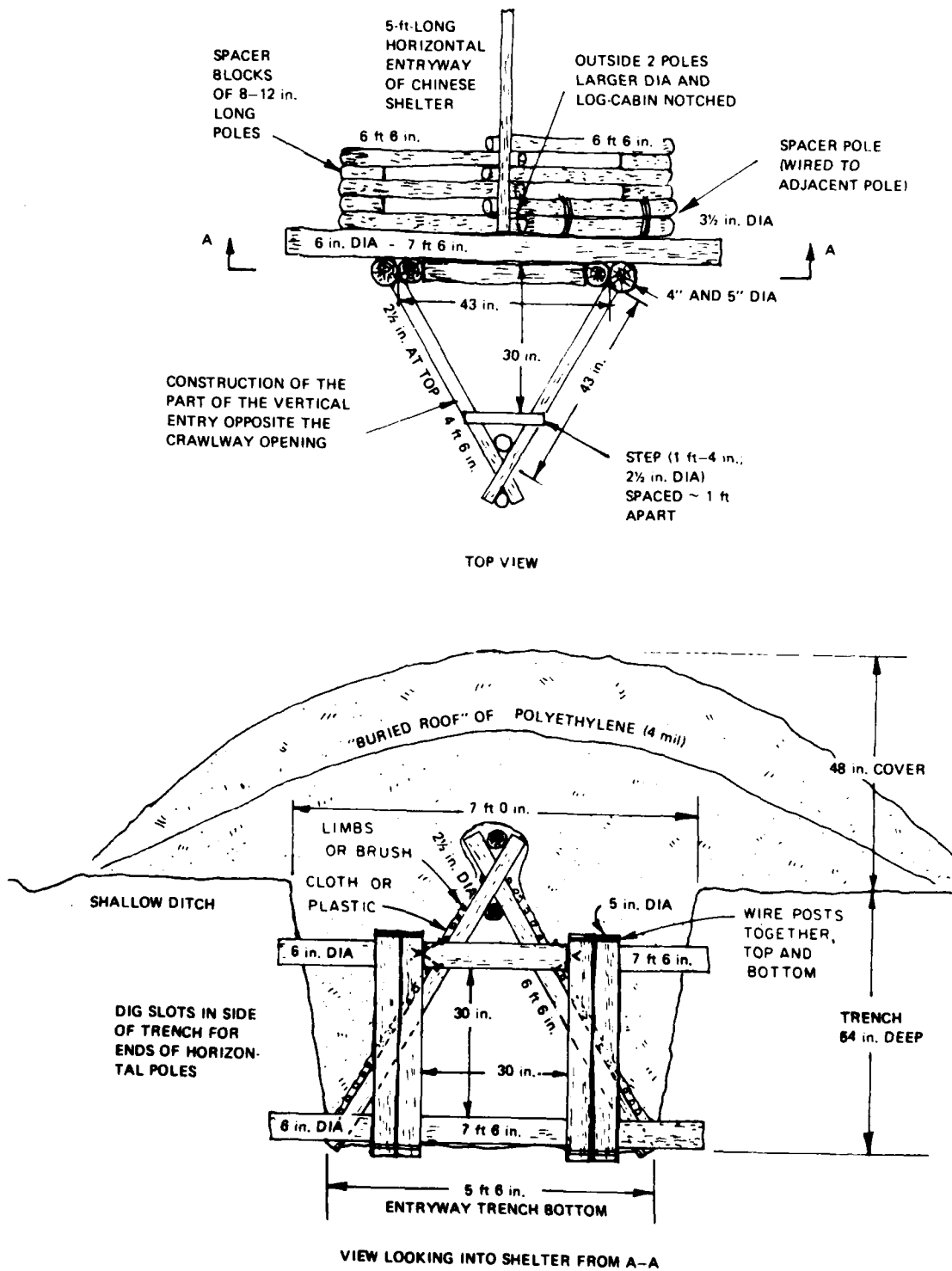
Fig. 7.4. Lower parts of the horizontal triangular crawlway and vertical entry of the Chinese A-Frame Pole Shelter.

ORNL PHOTO 4248-78

Fig. 7.5. Completed horizontal, triangular crawlway and start of the vertical part of the entryway.

2. a vertical, triangular entry made of small overlapping poles only on its two outer sides, with its open side providing access to the horizontal crawlway (see Figs. 7.4 and 7.5);

3. a triangular, vertical section made of overlapping horizontal poles on all three of its sides, extending to the surface (see Figs. 7.6 and 7.7); and

4. a triangular blast door made of hewn green poles (see Fig. 7.8).

Exposure of the door to six weeks of desert sun and heat had caused its poles to shrink, resulting in 1.3-cm-wide (1/2-in.-wide) shrinkage cracks between its poles. These were filled with cement slurry. (In an earlier blast test of this type of shelter,[2] two entryways were provided, one at each end. Two entryways, each with a blast door, are essential to assure adequate ventilation-cooling in warm or hot weather when only a low-pressure pump, such as a KAP, is available.)

After completing the "backpacking" of the shelter (see Fig. 7.9), it was covered with 1.2 m (4 ft) of untamped earth. The surfaces of the earth cover and the blast door were about level with the surrounding undisturbed earth.

Scratch gauges were mounted on a post set securely in a posthole dug in the foot trench of the shelter room. A plumb bob was hung from the ridgepole to measure its motion relative to a stake driven into the trench floor. Yielding foil membrane blast gauges and empty 1-gal cans were placed in the room and in the horizontal part of the entryway.

7.3 Test Results

Occupants of this shelter would not have been injured by the blast, with the exception of a person who might have been sitting with his head near the one wall pole that was broken (see Fig. 7.10). One wall pole and one pole closing the end of the shelter room were cracked. The rapid inward squeezing of the unshored, sloping earth walls of the foot trench near one end reduced its width from 30 cm (12 in.) to 10 cm (4 in.). This movement probably would have pushed occupants' feet upward, without hurting them (compare Figs. 7.3 and 7.11). The other end of the foot trench was partially collapsed.

ORNL PHOTO 4243-78

Fig. 7.6. Building the vertical entryway of small overlapping poles.

ORNL-DWG 79-18256

VERTICAL
BRACE POLES

HORIZONTAL
SIDE POLES
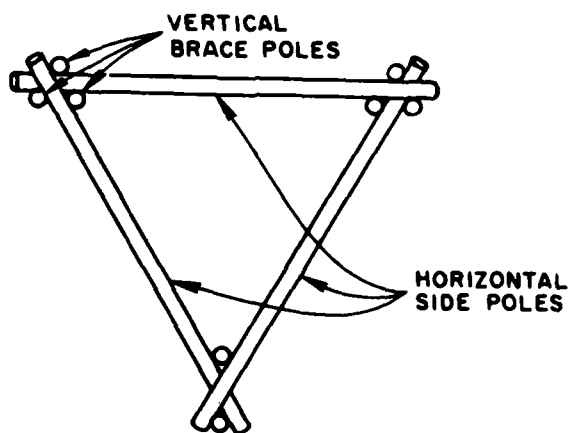
Fig. 7.7. Positioning of the horizontal side poles and vertical brace poles of the three-sided part of the vertical entry. The vertical brace poles were tightly bound together with No. 9. wire.

ORNL PHOTO 4260-78

Fig. 7.8. Preblast view of the expedient triangular blast door made of hand-hewn pine poles. Note the hinges made of strips cut from the treads of worn automobile tires, and the three blast-protector logs, which were notched and nailed together.

ORNL PHOTO 4242-78

Fig. 7.9. Improved Chinese A-Frame Pole Shelter almost completed, except for the vertical, triangular entryway. After the crushable "backpacking" had all been positioned, the top of the shelter room was covered with 1.2 m (4 ft) of earth, up to the original ground level and the top of the vertical, triangular entryway. (The rectangular structure in the background is not an expedient shelter.)

ORNL PHOTO 4169-78

Fig. 7.10. Postblast interior view of the room of the Chinese A-Frame Pole Shelter, showing the one wall pole that was broken. One wall pole of the end wall was cracked. Note the 1-gal can sitting upright, undisturbed by the blast, on the earth seat of the unshored lower part of the shelter The horizontal scratch gauge was broken, but the vertical scratch gauge, attached to the center post, was not.

ORNL-DWG 79-18258
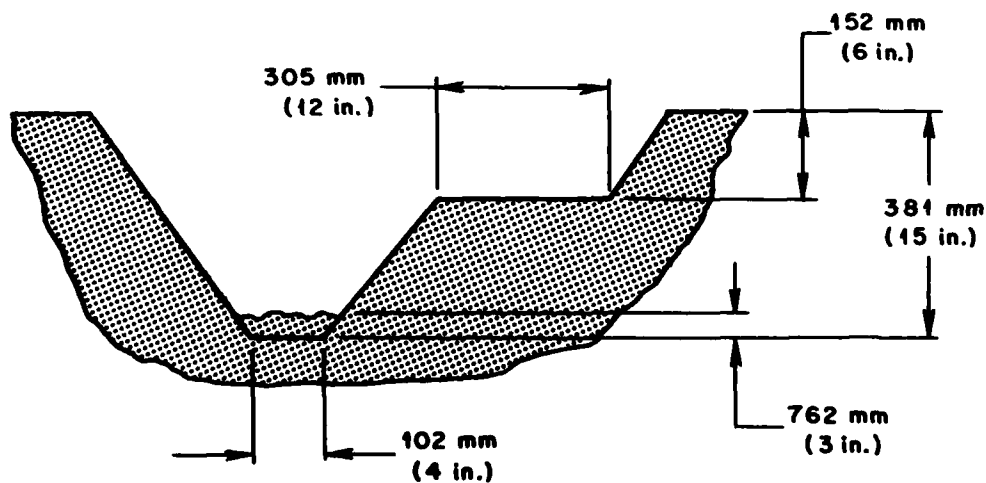
Fig. 7.11. Postblast dimensions of the unshored earth seat and foot trench.

The rise in air pressure inside the shelter was 27.3 kPa (3.95 psi), not high enough to cause injuries. Near the entrance the maximum overpressure was 23.3 kPa (3.37 psi). Outdoors, interpolation from the nearest measured overpressures indicated a blast overpressure of about 304 kPa (44 psi).

The blast door was undamaged, except as noted in the caption of Fig. 7.12. As a result of the two 60-penny nails at the lower ends of its hold-down wires having been torn loose by the negative overpressure, the blast door was jerked open by the "suction." Much dust was blown into the shelter. If the shelter had been occupied, it would have been necessary for someone to have gone outside after the explosion to shut the blast door.

The 1.3-cm-wide (1/2-in.-wide) cracks between the poles of the blast door, from which the cement fillings had been removed by blast effects, permitted enough air to rush into the shelter entryway to knock over the empty 1-gal can left standing in the entryway but not enough to dent any can.

Movement of the plumb bob relative to the trench bottom showed that the ridgepole had been lowered 7.6 cm (3 in.) and displaced 1.3 cm (1/2 in.) towards GZ. Apparently, blast-induced earth pressure had forced the poles of the wall nearer GZ somewhat deeper into the ground than were the wall poles of the side further from GZ.

The scratch gauge measurement data for the shelter room are given below:

Measurements from	Transient motion compression	Permanent motion compression
Top of post to ridgepole	8.7 cm (3-7/16 in.)	8.6 cm (3-3/8 in.)
Top of post to side toward GZ	8.6 cm (3-3/8 in.)	8.1 cm (3-3/16 in.)
Top of post to side away from GZ	8.7 cm (3-13/32 in.)	8.4 cm (3-5/16 in.)

As shown by Fig. 7.13, neither the lightly constructed vertical entryway nor its horizontal section was damaged at all.

The three blast-protector logs, each about 25 cm (10 in.) in diameter, were not moved laterally. They had been installed with their upper sides

ORNL PHOTO 3700-78

Fig. 7.12. Postblast view of the undamaged triangular, vertical entryway and its triangular blast door. The door was undamaged except for its having been inadequately secured shut with only two 60-penny [15-cm (6-in.)] nails (that were pulled loose by the negative-phase suction) and for having lost the cement that had been used to seal its cracks.

Fig. 7.13. Postblast view down the undamaged triangular, vertical entryway. The large hewn pole shown sloping to the left, in the upper left-hand corner of the photo, is the movable hinge pole of the door that closed against its fixed three-pole door frame.

only about 10 cm (4 in.) above the level of the surrounding ground. After the explosion these three blast-protector logs were almost on top of the ground. Nearby stakes showed very little blast wind erosion, with resultant lowering of the earth surface around them. Therefore it appeared that the logs had been pushed or squeezed up by forces in the earth, rather than largely uncovered by blast-wind erosion. The reason for the "jump up" of the blast-protector logs at 304 kPa (44 psi) has not been determined. [The four blast-protector logs around the rectangular blast door at 624 kPa (90 psi) were not raised.] However, the logs were effective in protecting the sides of the blast door from the high reflected overpressures to which otherwise they would have been subjected.

7.4 Conclusions and Recommendations

The short-duration overpressure and small impulse of this small explosion destabilized unshored earth walls some 2.4 m (8 ft) below the surface and caused them to be squeezed inward. This tends to confirm other blast test findings and theoretical calculations that indicate unshored earth walls (including the unshored lower part of the room of the Chinese A-Frame Pole Shelter) would be unsafe if subjected to the blast effects from a large nuclear explosion at an overpressure range higher than about 48 kPa (7 psi).

Since no similar shelter without "backpacking" was blast tested, the increased protection resulting from a covering of readily crushable material over a yielding shelter was not determined by MISERS BLUFF tests. However, other blast tests have demonstrated that covering machines with a thick layer of springy or crushable material greatly improves their survivability from severe blast effects, as compared with covering them with earth alone. Therefore, covering personnel shelters with a layer of brush or other springy material (such as straw, wood chips, or innerspring mattresses) several inches thick is likely to improve the blast protection they would afford.

Tests of expedient shelters at high overpressures with and without "backpacking" should be done at future blast tests.

The horizontal part of the entryway, if "backpacked," should withstand about 173-kPa (25-psi) blast effects from megaton-range explosions.

The triangular, vertical entryway, if "backpacked," should be undamaged by 345-kPa (50-psi) blast effects from a megaton-range explosion.

Since this triangular, vertical blast entry requires only small poles, people with instructions could build it in many wooded areas where the 4-m (13-ft) straight poles required for the blast entry of a Small-Pole Shelter would not be available.

Detailed instructions for making this triangular entryway and its triangular blast door should be developed and field-tested.

8. LIGHTLY CONSTRUCTED SHORED-TRENCH
SHELTERS AT 90 kPa (13 psi)

8.1 Purpose

If the population at risk were in shelters affording blast protection
up to the 103-kPa (15-psi) overpressure range rather than in typical
homes, the area in which most people would become casualties from blast
effects could be reduced about 85%. Therefore it is desirable to design
and blast test expedient shelters that afford up to 103 kPa (15 psi)
blast protection and require minimum materials, tools, and skill to
build.

Since expedient blast doors [giving at least 103 kPa (15 psi) blast
protection] had been tested successfully in earlier experiments,[1,2] only
the equivalent of detached, completely buried rooms of lightly constructed
shored-trench shelters were tested in MISERS BLUFF at the predicted 103-
kPa (15-psi) overpressure range.

8.2 Construction

To minimize costs and expedite construction, six designs of pole
trench-wall shoring for a covered-trench shelter were tested in a single
detached trench room 6.1 m (20 ft) long. Figure 8.1 shows a composite
cross section of several types of wall shoring that require a minimum of
widely available materials and that were tested in MISERS BLUFF, along
with weaker and stronger types. This composite shored-trench shelter had
the following design features (shown in Fig. 8.1): (1) the trench walls
are sloped; (2) the shelter has a low roof, but is of a height that has
been found practical for multiday occupancy;[8] (3) the width is slightly
greater than the narrowest shelters proved practical by occupancy tests;
and (4) the roof presses down on the surrounding earth but does not touch
or press down on any of the poles or other materials used for the shoring.

Unlike the mounded earth cover illustrated in Fig. 8.1, this detached,
composite shelter room tested at MISERS BLUFF had its roof poles positioned
0.9 m (3 ft) below the original ground level. Since the earth was very

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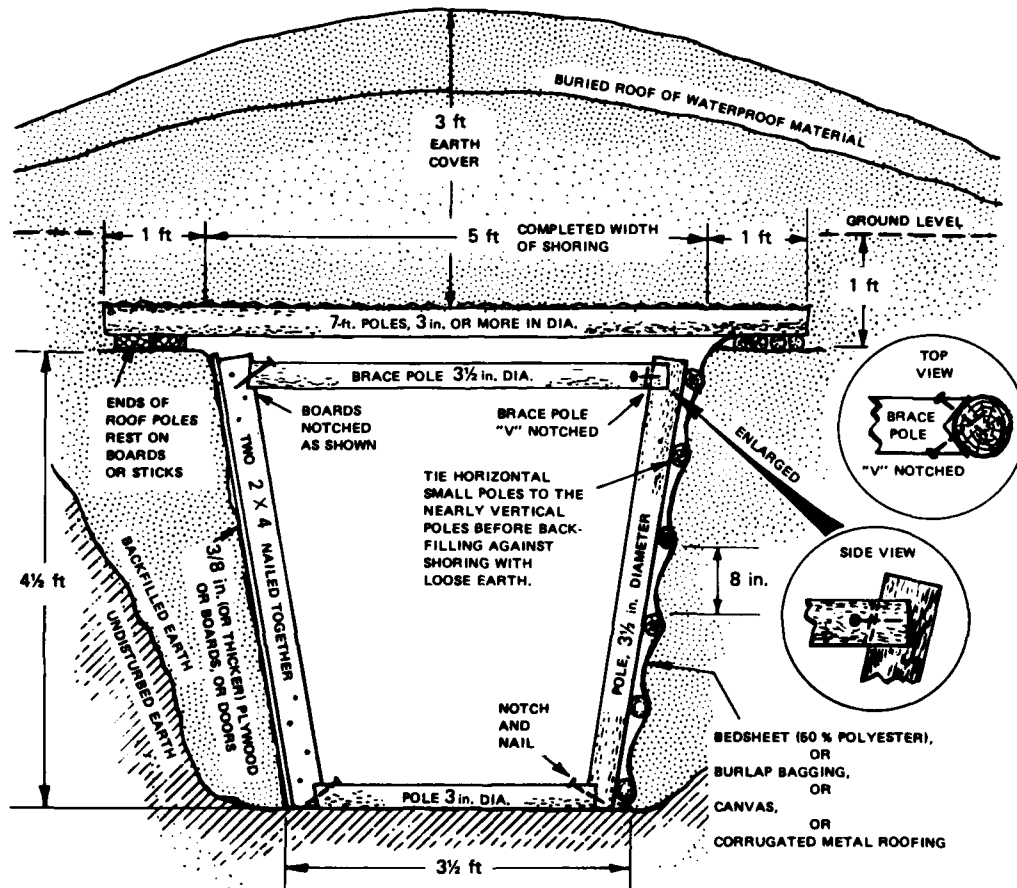
Fig. 8.1. A composite vertical cross section illustrating various ways to shore a Pole-Covered Trench Shelter, using a variety of widely available materials. A four-piece frame (consisting of four poles, or boards, installed as shown above) should be installed every 76 cm (2-1/2 ft) along the length of the trench. All parts of the shoring should be at least 5 cm (2 in.) below the roof poles, so that the downward forces on the roof will press only on the earth.

unstable, a wide trench was dug first. Then the trench shoring was built as a free-standing, small structure, as pictured in Fig. 8.2. Earth was then backfilled around the shoring to a height of about 7.5 cm (3 in.) above the upper horizontal brace poles of the shoring. Next the roof poles were laid so as to press on this earth surface. In the MISERS BLUFF test, on one side of the trench the roof poles were laid directly on the earth, and on the other side they rested on a 2 x 8 board used as a sill plate, as illustrated in Fig. 8.1. The roof poles were covered with dust-tight materials before being covered with 0.9 m (3 ft) of earth. No poles larger in diameter than 10 cm (4 in.) were used in any part of this composite shelter room.

The shoring materials on one side of the trench, which pressed against the trench walls, were poles positioned horizontally at different vertical spacings and covered with plywood or burlap bags on their outer sides. As indicated by Fig. 8.3, these bags kept the loose, dry soil from running through the openings or cracks between the horizontal shoring poles. On the other side of the trench, plywood alone was used outside the four-piece frames.

8.3 Test Results

No part of this completely buried, composite shelter room failed as a result of the stresses in the surrounding earth produced by the approximately 90-kPa (13-psi) blast overpressure at the surface (see Fig. 8.4).

A section of the weakest plywood (8.4 mm; 1/4 in. thick) that only pressed against its four-piece frames was bowed inward.

The ends of the roof poles that rested on the 2 x 8 board (that served as a sill plate on one side of the shelter) were pushed down significantly less than were their opposite ends that rested directly on backfilled earth.

8.4 Conclusions and Recommendations

Figure 8.1 summarizes the conclusions of the authors regarding the lightest practical trench-wall shoring that should be used to attain 103 kPa (15 psi) blast protection.

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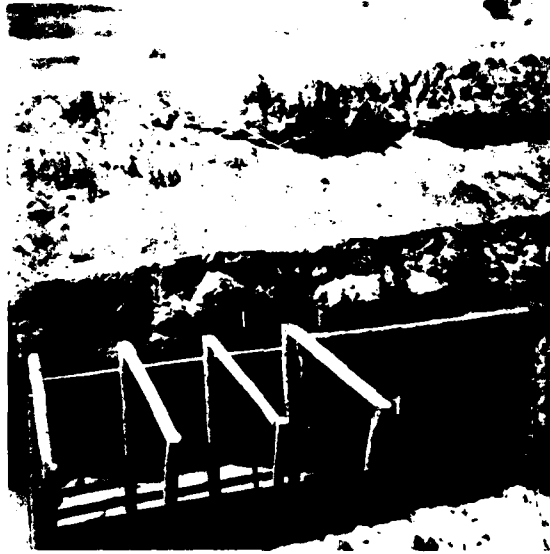
Fig. 8.2. Shored trench being built as a free-standing structure, to be surrounded and covered with very unstable, loose earth. The four-piece frames were spaced every 76 cm (2 ft 6 in.). On the nearer side, these frames pressed against plywood that was to be the shoring in direct contact with backfilled earth.

ORNL PHOTO 4240-78
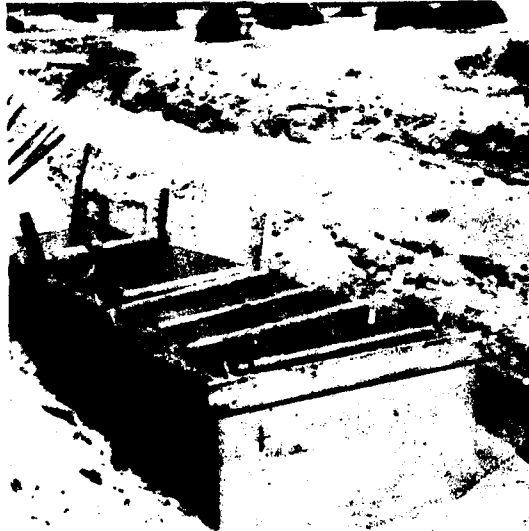
Fig. 8.3. The horizontal shoring poles of the nearer side pictured were covered on the outside with burlap bags to make them earth-tight when the loose earth was backfilled around the completed shoring.
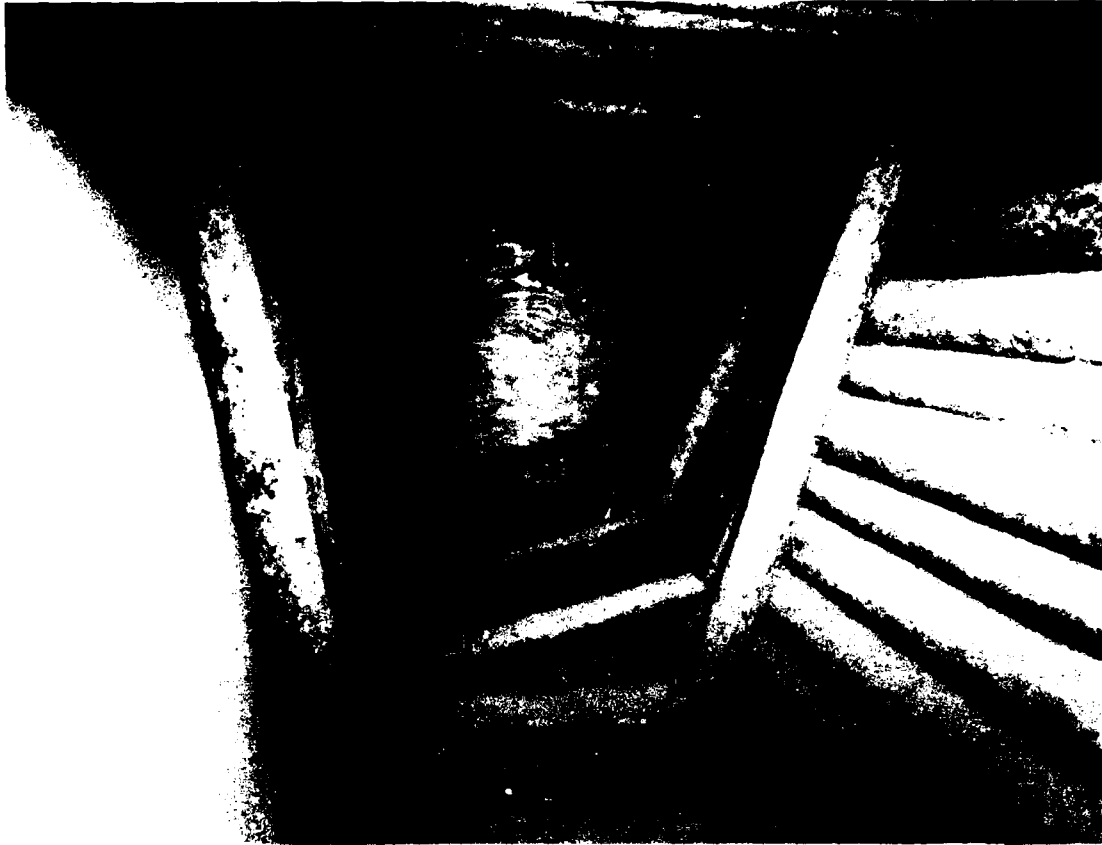
Fig. 8.4. Postblast view of about half of the pole-covered, shored-
trench shelter room, showing how four of its lower "horizontal" brace
poles were purposely installed incorrectly before the blast. These lower
"horizontal" braces of four frames were cut too long, so that when
installed they sloped as shown. Their higher, V-notched ends (see the
top view and side view insert sketches on the right in Fig. 8.1) were
merely nailed in these insecure positions. As anticipated, the small
impulse and reduced overpressure, produced by the small explosion in the
loose earth about 2.2 m (7 ft) below ground surface, did not exert enough
horizontal force on the shoring to loosen these incorrectly installed
lower brace poles.

Step-by-step, well-illustrated instructions for building shored-trench shelters should be written and then improved by successive field tests, so as to have them available for possible crisis distribution. Millions of Americans would need such help to improve their chances of surviving in extensive areas where most occupants of homes and buildings would be killed by blast, fire, or heavy fallout.

9. PLYWOOD A-FRAME SHELTERS AT 90 kPa (13 psi)

9.1 Purpose

Making an earth-covered A-frame shelter is a recognized and tested way[1,2] to resist blast stresses by using a minimum of materials while avoiding the complications of trench-wall shoring. Two such plywood A-frame shelter rooms were installed at the predicted 103 kPa (15 psi) overpresure range. Both of these detached rooms were of much lighter construction than any shelter of an A-frame type that had been previously tested. However, a small-scale model of similar design had been damaged but not collapsed by the earth pressures at the 1380-kPa (200-psi) overpressure range from a 5-ton TNT explosion.[6] Furthermore, useful information can be gained from the partial or complete failure of shelters largely dependent of earth arching for their survival if they are tested at higher overpressures than conventional calculations indicate they could survive.

9.2 Construction

The more sturdy of the two detached shelter rooms (room A) was built from standard-sized sheets of exterior-grade 3/4-in. (19-mm) plywood. Each sheet [122 cm (4 ft) wide x 244 cm (8 ft) long] was cut down to a length of 198 cm (6 ft 6 in.). Three of these shortened plywood sheets formed each side of the room. Rafters made of 2 x 4 boards (actually 1-5/8 x 3-1/2 in., or 41.4 x 88.9 mm) were nailed under the plywood sheets at the ends of the room and below the cracks between the six plywood sheets. The lower edges of the A-frame were 168 cm (5 ft 6 in.) apart when installed on the trench floor. The two ends of the A-frame were closed with pieces of 3/4-in. (19-mm) plywood (see Fig. 9.1).

The trench in which both the detached rooms were installed was excavated to a depth of 2.7 m (9 ft). A trench this deep permitted the tops of these shelters to be covered with 0.9 m (3 ft) of earth, with the top of the earth cover at the original ground level. This depth of excavation and coverage increases the blast protection afforded by shelters. In this way, their tops are 0.9 m (3 ft) below original ground
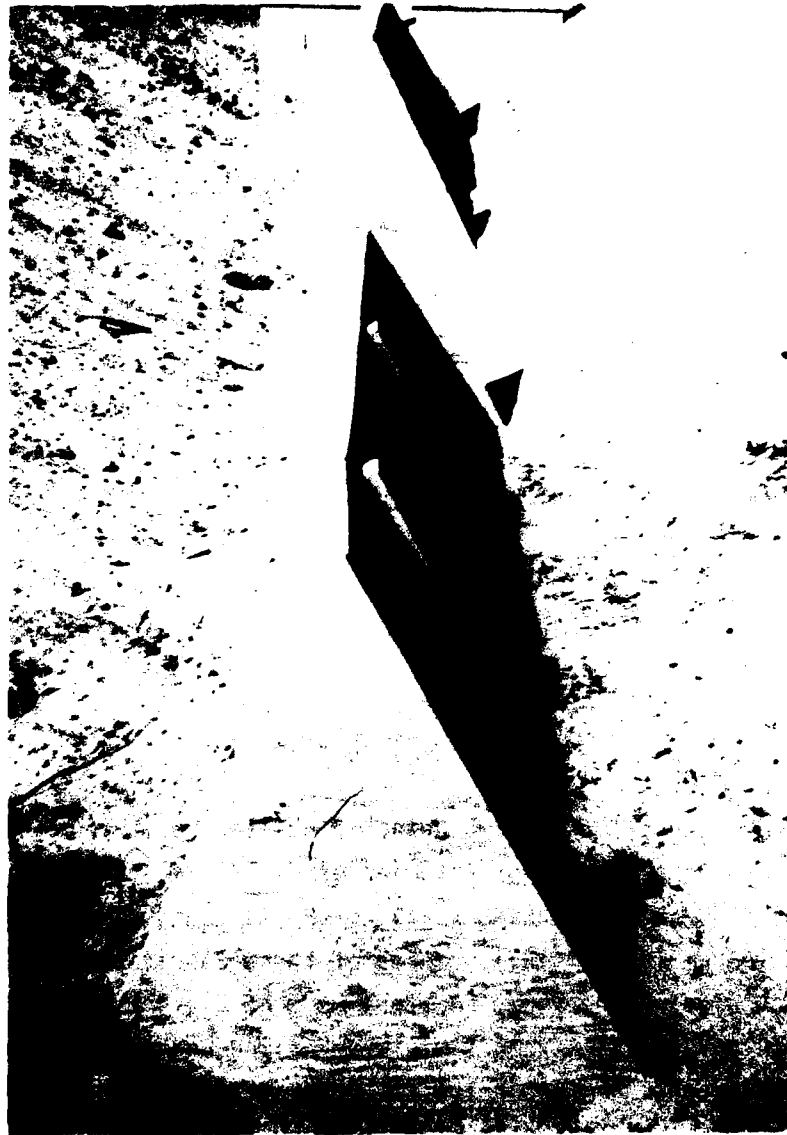
Fig. 9.1. Plywood A-frame shelters being covered with the dry, light, free-running earth of the test site. The detached room in the background had 2 x 4 rafters. The room in the foreground had no rafters; the boards pictured on top of its sides were merely laid over the cracks between plywood sheets to keep loose earth from running through.

level rather than being covered with 0.9 m (3 ft) of earth mounded above ground level. (Obviously, digging a trench about 2.7 m (9 ft) deep, in order to improve the blast protection of a shelter, militates against its practicality as an expedient shelter to be built by average Americans during a crisis.)

The weaker of the two detached shelter rooms (room B) had no rafters. Its six plywood sheets (same type and size as those used in room A) had their upper edges beveled for better fit. A 2 x 4 board was nailed near the upper edge of one side of the A-frame. This board was beveled so that the three plywood sheets of the other side could be nailed securely to it to form the A-frame. The same 168 cm (5 ft 6 in.) spacing of the lower edges of the A-frame was used as in room A. The ends were closed with plywood, as pictured in Fig. 9.1.

Room B partially collapsed while it was being covered, due to the weight of the dry, free-running, light earth.

9.3 Test Results

The blast overpressure of 90 kPa (13 psi) collapsed the middle part of room A, but the end parts of room A were not completely crushed by the blast effects from this small explosion. The blast completed the collapse of room B.

9.4 Conclusions and Recommendations

Neither of these two plywood shelters is strong enough to be recommended for use, even as a fallout shelter.

Considerably stronger designs of A-frame shelters made of plywood and lumber should be developed and blast-tested, so that in a possible crisis many citizens could make better use of these widely available materials.

[Note that even the stronger of the two shelters, room A, with 2 x 4 in. (41 x 89 mm) rafters spaced 1219 mm (4 ft) apart, is far below the structural specification for normal housing. Much greater strength could be achieved by using closer rafter spacing (406 mm, 16 in., normal practice) and stronger rafters such as nominal 2 x 6's or 2 x 8's (41 x 195 mm), or larger.]

10. EASIER WAYS TO PROTECT STORED WATER
AGAINST BLAST EFFECTS

10.1 Purpose

In earlier blast tests,[2,6] stored water had been successfully protected against severe blast effects by lining with polyethylene film both cylindrical and rectangular pits dug in stable earth and covering these lined pits with a flexible roof of plywood. These plywood roofs were covered with a sufficient depth of earth to attain effective earth arching. In the ORNL water storage test at the highest overpressures [365 kPa (53 psi)], the blast caused no loss of water stored in a cylindrical, lined pit with its plywood roof at ground level.[2] In a Boeing test at 1380 kPa (200 psi), no damage resulted to a filled, rectangular water storage pit with its plywood roof 0.6 m (2 ft) below ground level.[6]

The earth at the MISERS BLUFF site was almost flourlike; it was impossible to dig vertical-walled, stable-sided pits in this very loose, unstable soil. Such loose, unstable earth is characteristic of many areas where people would need to improve their chances of surviving a nuclear attack. At MISERS BLUFF we tested the following simple ways of storing water to protect it against all weapon effects.

10.2 Construction and Installation

At locations where the actual overpressures were about 145 kPa (21 psi) and 304 kPa (44 psi), sloping-sided pits were dug large enough to hold water containers made of ordinary polyethylene trash bags. Each container consisted of two 114-liter (30-gal) bags, one inside the other. After being placed in its pit, a double-thickness bag was filled with about 61 liters (16 gal) of water. Then the mouth was folded and tied shut, using a method that prior tests had found to result in minimum leakage. This method is indicated by Figs. 10.1 and 10.2 and is one of the many skills described in detail in Nuclear War Survival Skills, ORNL-5037.[9]

Four-wheel-drive vehicles could not operate in the almost flourlike, powdery alluvium of the test site. Figure 10.1 shows how water was

ORNL PHOTO 4002-78

Fig. 10.1. Water carrier ready to leave the road and efficiently carry about 32 kg (70 lb) of water to a test location.

ORNL PHOTO 4171-78

Fig. 10.2. About 61 liters (16 gal) of water inside two 114-liter (30-gal) plastic trash bags, ready to be roofed with plywood and covered with a mound of earth prior to being blast-tested at the 304-kPa (44-psi) overpressure range.

backpacked in two burlap bags, each lined with two larger plastic bags, to the test locations.

Figure 10.2 pictures two 114-liter (30-gal) plastic bags, one inside the other, placed in the ground at 304 kPa (44 psi) and filled with water by stages as the earth was filled in around them. Next, they were tied shut in a field-tested manner and covered with the piece of plywood, which was supported about an inch or two above the bags by the surrounding earth. Finally, earth was mounded about 0.4 m (16 in.) deep over the plywood rooflet and sloped at a low angle.

A simpler way of protecting stored water against severe blast effects was tested at 304 kPa (44 psi). A plastic-lined burlap bag holding about 30 liters (8 gal) of water (see Fig. 10.1) was merely placed in a shallow hole and covered with about 20 cm (8 in.) of the dry, powdery alluvium. This very light alluvium weighed only about 1290 kg/m^3 (80 lb/ft^3). Therefore, the pressure on the water bags was less than if they had been buried in a heavier free-running material such as dry quartz sand.

10.3 Test Results

No damage resulted to any of the water storage bags protected with plywood roofs, and only negligible leakage occurred through their tied-shut mouths in the few hours between the time of the explosion and the time they were examined (see Figs. 10.3 and 10.4).

The water bag that was merely covered with loose earth was undamaged. However, more leakage occurred through the tied-shut mouth of plastic bags that were merely covered with loose earth, than occurred out of the tied-shut mouths of bags protected by plywood roofs from earth pressure caused by overlying earth.

10.4 Conclusions and Recommendations

Double plastic bags and plastic-lined burlap bags are blast-survivable water containers if carefully tied shut and covered with a few hundred millimeters of earth. Tests of their ability to retain water for several days in loose, free-flowing soil should be made.

ORNL PHOTO 4163-78

Fig. 10.3. Postblast picture of the same water storage bags shown
in Fig. 10.2. Perhaps 0.5 liter (1 pt) of water had been squeezed out of
the tied-shut mouths of the plastic bags by the blast pressure and the
pressure from the surrounding powdery, light earth. (The two marker
stakes were driven after the blast.)

ORNL PHOTO 3988-78

Fig. 10.4. Using a bucket to bail water out of the plastic bags shown in Figs. 10.2 and 10.3. As the water level was lowered, the loose surrounding earth squeezed the sides of the bags inward, necessitating repeatedly digging the surrounding earth away as the bailing out of the water proceeded.

Water storage holes and pits should be roofed whenever plywood, boards, or sticks are available.

11. RAISABLE VENTILATION PIPE

11.1 Purpose

The air intake and exhaust openings of many blast shelters are merely fixed pipes that extend a few feet aboveground and have "gooseneck" upper ends to greatly reduce the intake of fallout particles. If typical urban, suburban, or wooded areas were subjected to severe nuclear blast effects, the blast-hurled beams, tree trunks, and other heavy debris would cause many such exposed ventilation pipes to break or bend. Likewise, the massive aboveground parts of typical Russian ventilation systems for blast shelters, their combined air intake and emergency exits, have drawbacks. These strong, quite massive aboveground structures would be likely to stop some blast-hurled debris, causing a pileup of combustible material beside them. In an area of severe blast and fire dangers, obviously a pile of flammable debris up against an air intake opening would be a hazard--especially if it smoldered rather than burned, as Russian civil defense books describe the fires in areas of almost complete blast destruction of aboveground buildings.

The idea of having raisable ventilation pipes so designed that they could be raised above ground level by the shelter occupants after the blast is an old one. However, since the authors could find no record of such pipes having actually been made and tested, a raisable ventilation pipe was designed, made in a small machine shop, and installed in the Small-Pole Shelter before it was tested at 621 kPa (90 psi). (Raisable ventilation pipes are not expedient equipment. Nevertheless, since dependable, low-cost means for assuring adequate postblast ventilation for blast shelters is a neglected problem, this exploratory test was included.)

11.2 Construction

Figure 11.1 shows the raisable ventilation pipe after the blast and after it had been raised above ground level. Because the fixed housing pipe around the raisable ventilation pipe was about 0.2 m (8 in.) too

ORNL PHOTO 3996-78

Fig. 11.1. Upper part of raisable ventilation pipe after it was jacked up above ground level after the blast. Its spring-loaded, hinged hood opened to form a hooded air opening as soon as the bottom of the hood was raised above the top of the fixed housing pipe. Note the bent steel fence post touching the handle of the hammer. The shock wave and approximately 2253-km/h (1400-mph) blast wind bent this steel marker post.

long for the depth below the original ground level at which the Small-Pole Shelter was installed, the light, dry earth was mounded only a few inches deep over the loose steel cap that covered the housing pipe rather than the recommended 9 in. The blast winds blew away the dry earth down to the level pictured in Fig. 11.1; the steel cap was blown away and lost.

The high-lift jack (see Fig. 11.2) easily raised the ventilation pipe after the blast. The 76 x 102 mm (3 x 4 in.) hole near the upper end of this pipe was covered with a piece of steel cut from a section of 114-mm-diam (4-1/2-in.-diam) pipe. This piece, 184 mm (7-1/4 in.) long, was connected with hinges at its top to the ventilation pipe and was spring-loaded so that, unless held against the pipe, it opened to form the hooded opening shown in Fig. 11.1. To cause most particles to fall past the hooded opening, the whole upper part was covered with strong nylon canvas. (A fireproof, melt-proof flexible cover should be used to prevent possible damage by thermal-pulse heat radiation from even a quite distant nuclear explosion after the ventilation pipe is raised.)

Usually, with expedient shelters built in a hurry under crisis conditions, the depth of the trench and the thickness and side slopes of the earth cover would not result in the ventilation pipe and its steel-pipe housing being the optimum lengths. If all measurements had been optimum, the 3175-kg (7000-lb) high-lift jack, with a maximum lift of 97 cm (38 in.), would have raised the top of the ventilation pipe, if originally 23 cm (9 in.) below the earth cover, about 74 cm (29 in.) aboveground. [If even loose earth is at the same elevation as the flat surrounding ground, blast-wind erosion (scouring) is negligible.]

Figure 11.3 indicates how the ventilation pipe, after being raised, was held in place. Except for the lost cap on the housing pipe, the blast caused no damage to this ventilation pipe.

11.3 Conclusions and Recommendations

Constructing ventilation pipes for expedient shelters is not practical under the hurried, stressed conditions of a worsening crisis.

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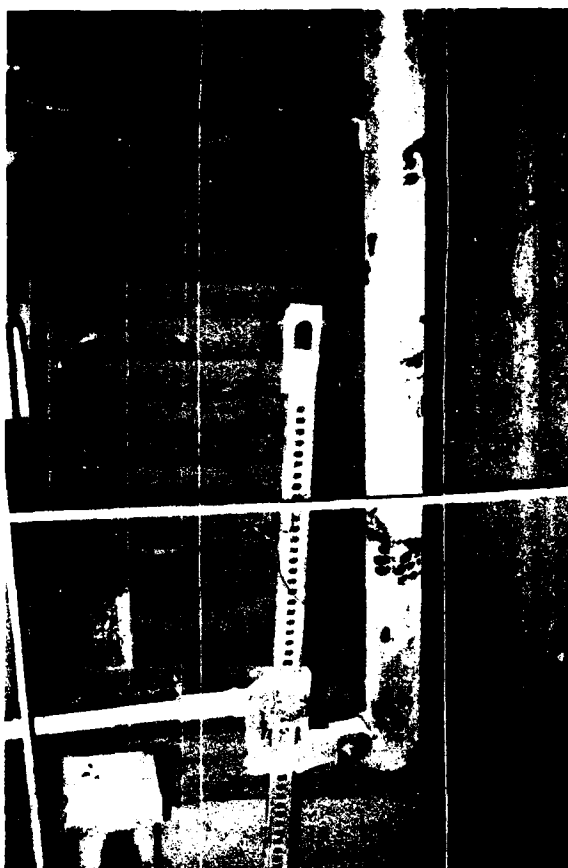
Fig. 11.2. Ordinary high-lift jack being used to jack up the raisable ventilation pipe after the blast. The horizontal, full-diameter opening in the lower end of the ventilation pipe faced away from the camera and therefore is not visible in this photograph.

Fig. 11.3. View looking upward at the raisable, 76-mm (3-1/2-in.) internal-diameter ventilation pipe going through its hole in two oversize roof poles. The hanging loop of light steel cable was attached to the steel support flange at the bottom of the 127-mm (5-in.) internal-diameter housing pipe. After the pipe had been raised, the loop was placed over the hook (see Fig. 11.2) welded to the pipe, so that the pipe could be held in its raised position and the jack could be removed.

Raisable ventilation pipes may be practical for permanent blast shelters having blowers or other types of ventilation pumps capable of supplying adequate outdoor air through pipes a few inches in diameter.

There is a need to design and blast-test dependable, safe ventilation systems for expedient shelters in areas likely to be subjected to severe blast and heavy fallout.

12. SUMMARY OF THE MISERS BLUFF BLAST TESTS
OF EXPEDIENT SHELTERS

Type of shelter	Overpressure	Depth of earth cover	Results
Small-Pole Shelter (Russian-style main room with a solid floor of poles and a horizontal walk-in entryway, with ORNL-designed vertical entry and blast door) Rectangular construction	621 kPa (90 psi)	1.5 m (5 ft)	No damage to structure Blast door badly damaged but withstood positive pressure Blast door opened by negative pressure
Small-Pole Shelter (only a Russian-style main room with typical earth floor) A rectangular detached room completely buried	621 kPa (90 psi)	1.5 m (5 ft)	No damage to structure Some upward flow of the destabilized earth floor, 15 cm (6 in.) maximum
Chinese A-Frame Pole Shelter with ORNL-designed vertical entry and blast door Triangular construction	304 kPa (44 psi)	1.2 m (4 ft)	One pole in main room broken Two poles in main room cracked *Blast door opened by negative pressure* Some flow of destabilized earth in unshored trench in main room, reducing its width up to 66%
Shored-Trench Shelters Three sections Six kinds of wall shoring	90 kPa (13 psi)	0.9 m (3 ft)	No damage to structures Some inward bowing of weakest plywood wall
Plywood A-Frame Shelter 2 x 4 rafters 1.2 m (4 ft) on centers	90 kPa (13 psi)	0.9 m (3 ft)	Partial collapse of center section End sections damaged but survived
Plywood A-Frame Shelter No rafters	90 kPa (13 psi)	0.9 m (3 ft)	Partial collapse during back-filling Total collapse during event

13. PRINCIPAL CONCLUSIONS

The improved Small-Pole Shelter tested at 621 kPa (90 psi) should afford its occupants adequate protection up to 350 kPa (50 psi) against all effects of a 1-megaton or larger explosion--if additional shielding against initial nuclear radiation is provided as outlined.

The improved triangular, vertical entry made of small poles, part of the improved Chinese A-Frame Pole Shelter tested at 304 kPa (44 psi), should provide adequate protection against large nuclear weapons at the 273-kPa (25-psi) overpressure range. (This design of entry requires minimum materials and could be used with other, stronger shelter rooms.)

The improved horizontal entry of the improved Chinese A-Frame Pole Shelter should withstand 273-kPa (25-psi) blast effects from a megaton-range explosion.

The unshored lower walls of the main room of the improved Chinese A-Frame Pole Shelter probably would be squeezed in or collapsed at much lower overpressures than 304 kPa (44 psi)--perhaps at overpressures of only slightly more than 48 kPa (7 psi) from a megaton-range explosion.

The pole-covered trenches with the strongest wall shoring tested at 90 kPa (13 psi) should provide adequate protection from large weapons at this overpressure and probably at 104 kPa (15 psi).

14. PRINCIPAL RECOMMENDATIONS

For more dependable evaluations of blast shelters that rely on earth arching for a large part of their resistance to blast, such shelters should be tested under conditions simulating the blast effects of a nuclear explosion having a yield of at least 100 kilotons.

Step-by-step, well-illustrated instructions for building and using the best designs of expedient blast shelters should be prepared and thoroughly field-tested under simulated crisis conditions. These instructions should then be supplied to all civil defense directors and given to all citizens requesting copies.

Appendix A

OVERPRESSURES MEASURED INSIDE DONN CORPORATION STEEL SHELTERS
AND DETACHED ENTRANCES, AND INSIDE ORNL EXPEDIENT SHELTERS

Shelter or entrance, at predicted overpressure	Membrane 1 1-in. diam (psi)	Membrane 2 1-in. diam (psi)	Membrane 3 1-1/2-in. diam (psi)	Membrane 4 1-1/2-in. diam (psi)	Membrane thickness
DONN shelter 150 psi room	0.1	0.1	0.93	2.79	1 mil
DONN shelter 100 psi room	2.12	2.31	2.20	2.50	1 mil
DONN shelter 50 psi room	1.04	1.22	1.08	1.28	1 mil
DONN shelter 50 psi vertical entrance	3.83	3.91	4.30	3.91	1 mil
DONN shelter 100 psi detached entrance #3	2.17	0.1	7.15	4.45	5 mils
DONN shelter 100 psi detached entrance #4	4.78	5.22	6.76	6.96	5 mils
DONN shelter 50 psi detached entrance #1	7.83	8.70	6.96	6.57	5 mils
DONN shelter 50 psi detached entrance #2	8.70	4.78	4.64	6.18	5 mils
DONN shelter 15 psi (Gothic arch shelter)	1.65	1.22	1.12	1.16	1 mil
Small-Pole shelter detached room 100 psi	3.75	3.75	3.66	3.80	1 mil
Small-Pole shelter center of room 100 psi	4.23	4.44	3.69	3.82	1 mil
Small-Pole shelter entryway near entrance 100 psi	4.00	4.00	3.68	3.80	1 mil
Chinese A-frame pole shelter room 50 psi	3.84	4.00	3.96	3.99	1 mil
Chinese A-frame pole shelter entrance 50 psi	3.16	3.37	1.76	2.09	1 mil

Appendix B

PHOTOS OF SOME DONN CORPORATION CORRUGATED
STEEL SHELTERS TESTED IN EVENT II-I OF MISERS BLUFF

ORNL PHOTO 4249-78

Fig. B.1. Some of the assembled parts of a vertical and horizontal
entryway of a Donn Corporation steel shelter being carried to the instal-
lation trench. No disassembled part of a Donn shelter weighs more than
22.7 kg (50 lb).

ORNL PHOTO 4245-78
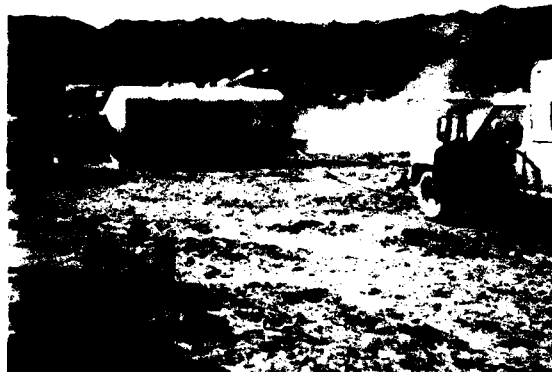
Fig. B.2. Complete shelter room being rolled, preparatory to being lowered into its trench by the ropes connected to the pickup truck. For compactness and ease of transporation and storage, all parts are 180° segments of a cylinder, designed so that unskilled workers can quickly bolt them together.

ORNL PHOTO 4244-78

Fig. B.3. Complete shelter room in its roughly bulldozed installation trench. One of the complete rooms was merely rolled--not lowered--into its trench, with no resultant damage. The diameter of the room is 2 m (6 ft 6 in.). Each of the seven semicylindrical rings is 0.6 m (2 ft) wide.

Fig. B.4. A completely assembled Donn Corporation steel blast shelter in its trench, being covered with 1.2 m (4 ft) of earth. With its improved blast door and blast valve (successfully tested in MISERS BLUFF, Event II-II), this shelter should give reliable protection against all blast effects of large nuclear explosions up to the 345-kPa (50-psi) overpressure range. Protection against all radiation dangers should be good--except for those resulting from the probable postblast entry of some windblown fallout particles through the open blast valves, which are only a few inches above ground level.
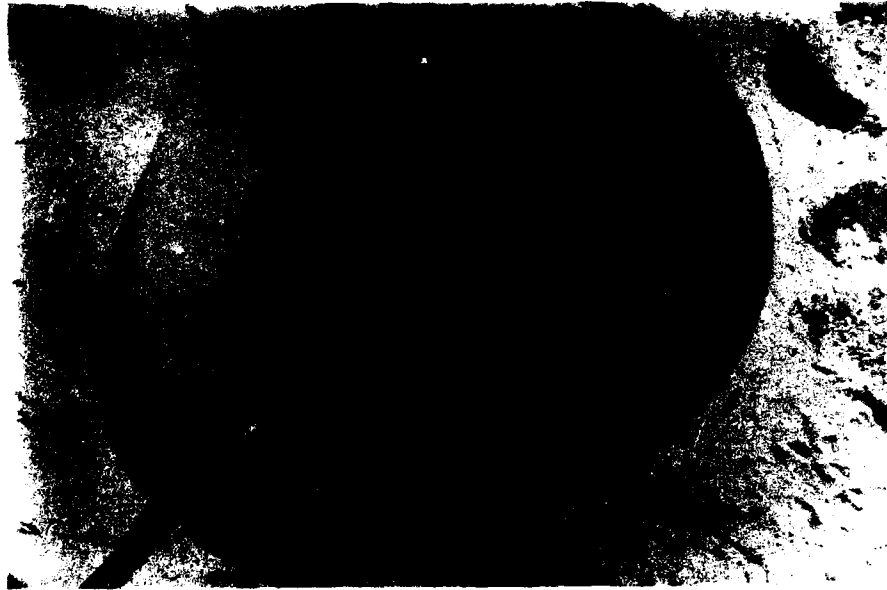
Fig. B.5. Blast door and entry tested at approximately 621 kPa (90 psi) overpressure--at the distance from GZ predicted for 690 kPa (100 psi). The blast pressure bent this door down in the middle, opening a crack 7.0 cm (2-3/4 in.) wide along its hinge line at its center. Loose, dry earth ran through this large crack until a cone-shaped hole was formed on the surface. The blast pressure also pushed down the entire entryway about 0.3 m (1 ft), by compressing the vertical entryway's corrugations, like an accordian's pleats.

ORNL PHOTO 4174-78
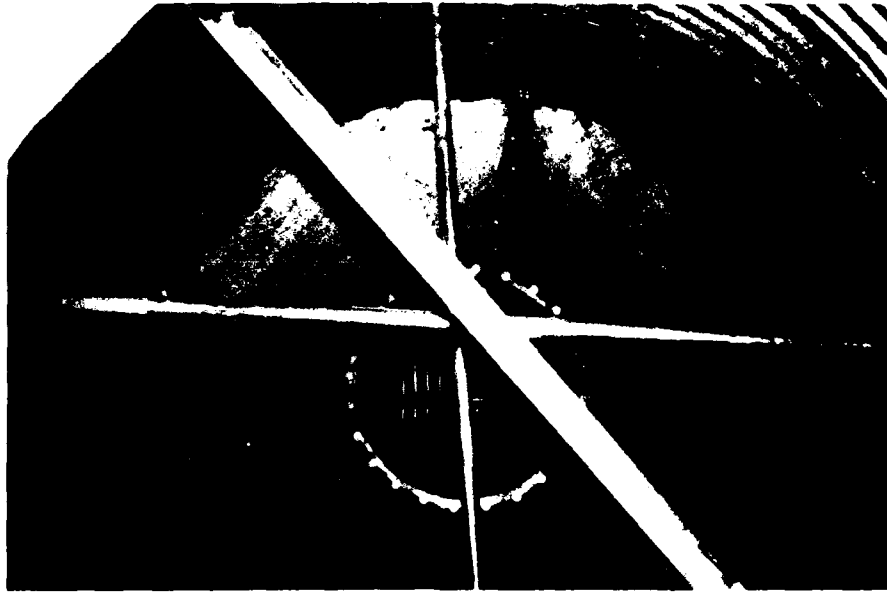
Fig. B.6. Preblast view of the interior of the shelter room later tested at 621 kPa (90 psi), looking out the crawlway entrance. Post-blast readings of the scratch gauges recorded a decrease of 8.5 cm (3.3 in.) in the vertical diameter of the room and an increase of 7.6 cm (3.0 in.) in the horizontal diameter.

Fig. B.7. Improved A-frame steel fallout shelter being completed as a detached room. It was covered with 0.9 m (3 ft) of earth at the predicted 104-kPa (15-psi) overpressure range. Unlike the plywood shelter pictured in the foreground, this steel shelter did not collapse, although the whole shelter was driven downward 15 cm (5.6 in.). Footings are needed under the thin lower edges of this simple, quickly installable, steel fallout shelter, since even without blast loading, it may be slowly driven down into soft earth by the weight of shielding earth on top of the shelter. Furthermore, in an earlier blast test (ref. 2) a scale model of an ORNL Chinese A-Frame Pole Shelter was pushed about halfway into the ground by blast effects equivalent to those of a 1-kiloton nuclear explosion at 214 kPa (31 psi).

Two-inch boards (actually 1-5/8 in., or 41 mm, thick) should serve well as footings, especially if of soft wood that would permit the thin lower edges of the steel shelter to press into them slightly. A "2 by 4" board (actually 3-1/2 in., or 89 mm, wide) should be wide enough for a footing of this small shelter. Some downward movement of the loaded shelter is desirable to promote protective earth arching over and around the structure.

ORNL PHOTO 4827-78
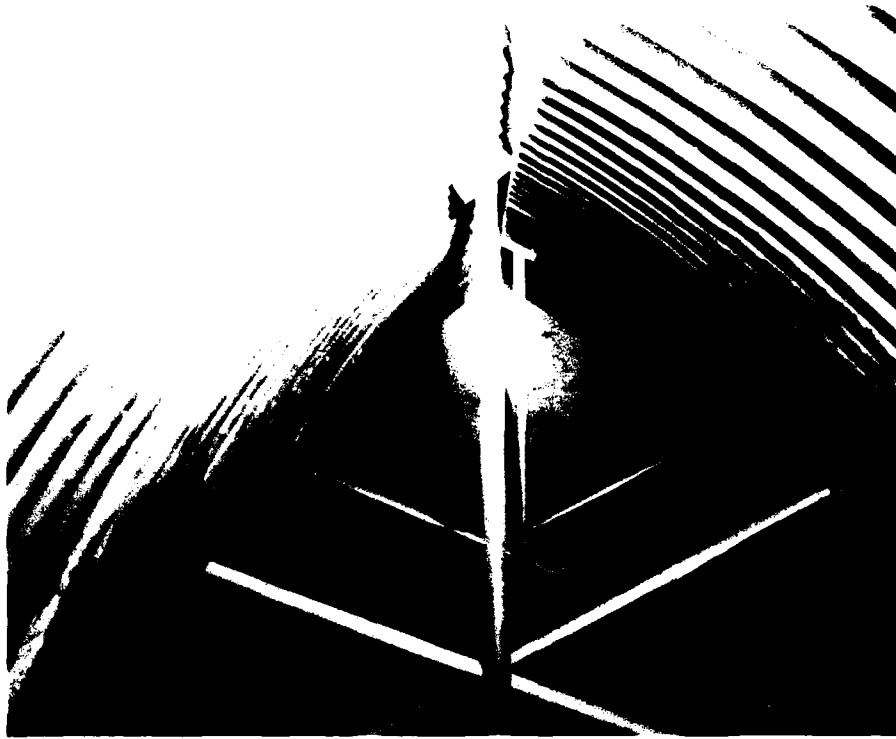
Fig. B.8. Postblast interior of the A-frame fallout shelter. The blast pressures reduced the width by only 4.0 cm (1.6 in.).

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ABSTRACT

Expedient shelters were blast-tested by a conventional explosion equivalent to a 0.2 KT nuclear explosion. The estimated survivabilities in a large nuclear explosion are: (1) improved Small-Pole Shelter, 345 kPa (50 psi); (2) triangular entryway and blast door made of poles, 173 kPa (25 psi); (3) Chinese A-Frame Pole Shelter, 48 kPa (7 psi); and (4) lightly shored Pole-Covered Trench Shelters, 103 kPa (15 psi).